A Conceptual Framework and Technical Approach For Assessing Instream Flow Needs In the Water Resources Inventory Area No. 1 (WRIA1) in Washington State

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Introduction

The entire Nooksack River basin and certain adjacent streams comprise the Water Resources Inventory Area No. 1 (WRIA 1) in Washington State. The challenges facing water resources management within WRIA1 is complex and include issues related to limited water supplies to meet current and future needs, water quality degradation, and the listing of Chinook salmon and bull trout as "threatened" under the Endangered Species Act (ESA). These issues have a broad and far-reaching affect on the economic and environmental health of the communities within WRIA 1. Under the auspices of the Watershed Management Act (RCW 90.82), a collaborative effort to address these issues is being led by Whatcom County, City of Bellingham, Public Utility District No. 1 of Whatcom County, Lummi Nation, and the Nooksack Tribe. This effort is focused on the development of a comprehensive watershed management plan. The watershed management plan is being developed in phases. Initially, a technical assessment is being conducted in order to provide a framework to better understand the nature and extent of water resource management issues. Based on this technical assessment, WRIA 1 Watershed Management Project participants and other entities will locally plan and implement solutions to identified problems. The WRIA 1 Watershed Management Project will address the requirements of ESHB 2514 for water quantity assessments as well as addressing related issues of water quality, instream flow, and fish habitat. This effort is being coordinated with other water resource dependent activities such as the salmon restoration actions (ESHB 2496). This document addresses the instream flow component of the WRIA 1Watershed Management Project.

Instream Flow Component of the WRIA 1 Watershed Management Project

This document outlines a strategic process and framework under which the specific objectives of the instream flows component of the WRIA 1 Watershed Management Project can be met in a manner that ensures that the related technical issues are resolved through a process of verification and validation. The document also stresses the critical linkages between the instream flow and other components of the Watershed Management Project such as water quantity, water quality, and related salmon restoration activities. The process outlined to assess instream flows considers important linkages such as strategies for field collection of pertinent physical, chemical, and biological data; various data analyses and modeling efforts; and the integration of these efforts with other components to meet the overall objectives of the WRIA 1 Watershed Management Project. The framework and technical approaches described below for instream flow assessments represent an application of multi-disciplinary assessment approaches to river ecosystem problem solving. The conceptual framework also maintains a strong technology transfer component as part of the overall mission of the Utah Water Research Laboratory (UWRL) and the Institute for Natural Systems Engineering (INSE). To the extent possible, the existing research strategies of various agencies were considered in the selection of specific approaches outlined in this framework. Although specific technical approaches have been identified for the various components of instream flow assessments, it must be stressed that the selection and application of specific techniques or approaches will be identified within the process and does not preclude the use of alternative approaches where appropriate.

Background and Assumed Study Objectives

In the most simplistic sense, the principal objectives of the proposed instream flow assessment for WRIA 1 are to:

Develop an analysis framework and technical approach that can be used to assess instream flow needs in light of natural, historical, existing, or proposed management decisions.

Develop this framework in a manner that can integrate (or be integrated with) on-going aquatic resource management and restoration objectives in WRIA 1 for anadromous species or other flow dependent resources (e.g., resident species, recreation).

Develop this framework in a manner that supports the integration of other critical watershed activities such as municipal, industrial, agricultural, forestry, and related land use planning and management.

In order to meet these objectives, an empirical based approach that focuses on development of an understanding of the key physical, chemical, and biological processes in light of specific land use settings should be a primary focus. Reliance on empirical data to the extent practical also inherently includes a strong verification and validation component to the study plan. This ongoing verification and validation process will allow adaptations to the strategic plan to best meet the stated objectives. The efforts should be undertaken in a manner that is amenable for use in long term monitoring within the context of adaptive management. The adopted methods should be as quantitative as feasible given current state-of-the-art capabilities at the demonstrated application level versus a research based orientation. There will likely be a need for specific research that is focused on specific technical issues in order to understand and/or quantify key physical, chemical, or biological process and their interdependence as a natural outcome of the proposed framework and its implementation.

To assist in the identification of specific technical approaches appropriate for use in WRIA 1, an Instream Flow Methods Conference was held that involved a twelve person Technical Team comprised of experts in the various scientific disciplines related to instream flow (See Attachment A). Other interested parties associated with the WRIA 1 Watershed Management Project also participated in the conference. Dr. Thomas Hardy of Utah State University was unanimously selected by the WRIA 1 Staff Team and Administrative Decision-Makers of the five Initiating Governments to be the General Chairperson for the conference. The objective of this conference was to provide a forum for technical discussions and consensus building by the Technical Team on the most appropriate method(s) for estimating an accurate relation between stream flow and fish habitat quantity and quality in WRIA 1. The conference participants addressed five main topic areas: stratification, hydrology methods, field data collection methods, habitat modeling, and habitat suitability criteria/indices. This document relies heavily on the majority consensus of the Technical Team for these topic areas. Prior to outlining the proposed framework and a discussion of specific technical elements, the following section provides a general overview of multi-disciplinary assessment frameworks for instream flow assessments in order to set the context for the remainder of the document.

Background on Multi-Disciplinary Assessment Frameworks

The four major components of a stream system that determine productivity for aquatic organisms are: (1) flow regime, (2) physical habitat structure (e.g., channel form and substrate distribution), (3) water quality (e.g., temperature, dissolved oxygen), and (4) energy inputs from the watershed (e.g., nutrients and organic matter). The complex interaction of these components determines primary production, secondary production, and ultimately the status of fish populations in a stream reach. In riverine systems, the amount and quality of suitable habitat can be highly variable within and among years. The observed population and biomass of fish and invertebrates may be depressed or stimulated by numerous preceding habitat events. Habitat induced population limitations are related to the amount and quality of habitat available to fish and invertebrate populations at critical stages in their life history. Long term habitat reductions, such as reduced flows, may also be important in determining population and production levels.

River ecosystems create a temporally and spatially variable physical, chemical, and biological template within which fish and other aquatic resources can exist if they possess the proper suite of physiological, behavioral, and life history traits (Poff and Ward, 1990; Orth, 1987). This species-specific set of traits is often characterized as a multi-dimensional niche of environmental conditions (e.g., ranges or limits of depth, velocity, substrate, temperature) and resources (e.g., food, space) that describes the environmental conditions necessary for species survival. Suitable environmental conditions and resources must be available in terms of their quantity, quality, and timing in order to sustain a viable long-term population (Statzner and Hilger, 1986; May and MacArthur, 1972; Pianka, 1974; Colwell and Futuyma, 1971). Because a variety of factors (e.g., environmental conditions and resources) are required to meet the life history requirements of species, the short and long term success of individuals and ultimately populations can be limited by a single factor or by a combination of factors.

In river systems, the suitability of environmental conditions for aquatic resources is directly related to the characteristics of the flow regime. Therefore, quantification of a flow regime which will provide long-term protection of the aquatic resources must be undertaken (1) by identifying the environmental conditions that operate to limit aquatic species, and (2) identifying a flow regime that will ensure the formation and persistence of key environmental conditions.

Most quantification methodologies currently recognize that suitable flow regimes can be broken down into four basic flow components as shown in Figure 1 (Petts et al., 1995; Hill et al., 1991). These four flow components are fish habitat base flows, fish habitat maintenance flows, riparian maintenance flows, and valley maintenance flows. Although the specific methods by which these flows are quantified may be subject to debate, these flow components are essential to maintain the ecological health of the stream system (Hill et al., 1991). Quantification of fish habitat base flows, fish habitat maintenance, and riparian maintenance flows are likely the most critical components. Valley forming flows are typically not quantified from a pragmatic perspective since they represent catastrophic flood events, which occur only infrequently and are associated with property damage.

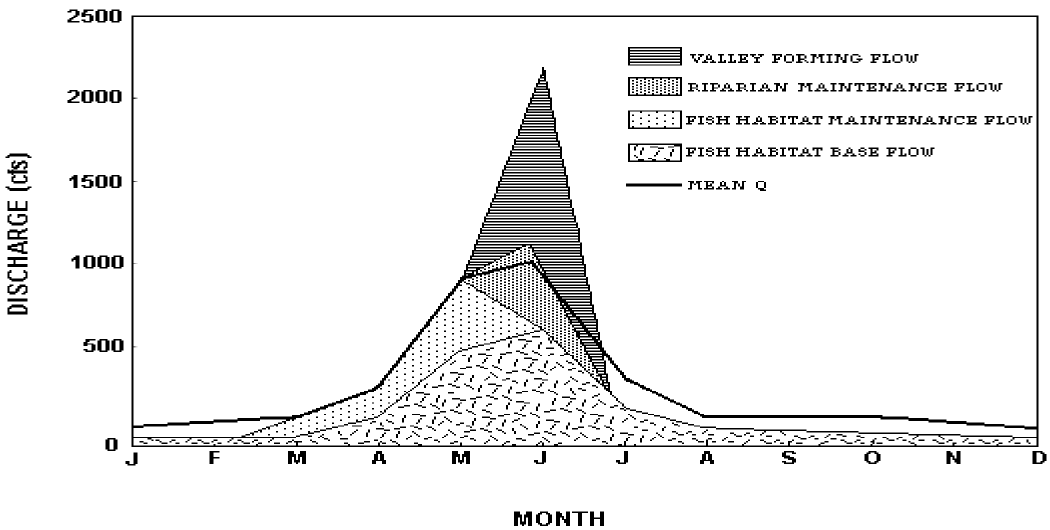


Figure 1. Flow Components of an Ecological Flow Regime.

In recent years, instream flow assessments have incorporated a broad focus on the river corridor as an integrated ecosystem (Goodwin and Hardy, 1999). This ecosystem approach has led to research on methods for delineating the linkages between flow, sediment transport, channel structure, and the riparian community (Hill et al., 1991; Nillson et al., 1991; Rabeni and Jacobson, 1993; Stromberg et al., 1991; Stromberg, 1993). This research includes the delineation of the flow dependent characteristics of macroinvertebrate community dynamics and the linkage between macroinvertebrates and fish (Lancaster and Hildrew, 1993; Gore, 1989; Jowett et al., 1991; Weisberg et al., 1990; Statzner and Hilger, 1986, Filbert and Hawkins, 1995; Bevelhimer, 1996; Weisberg and

Burton, 1993; Easton and Orth, 1992; Roell and Orth, 1994). These efforts have resulted in assessment frameworks oriented at the quantification of ecologically based flow regimes that address the needs of the entire river corridor (e.g., base flows, riparian, and fish habitat maintenance flows).

The recognition of the importance of including fish habitat and riparian maintenance components in an ecologically based flow regime has arisen from research that links the role of high flows with geomorphic and ecological responses of river corridors. Beschta and Platts (1986) reviewed the ecological functions of the primary geomorphic attributes of small streams. They emphasized the role that different geomorphic features play in the life history of fish, and demonstrated that most of the geomorphic features are formed and maintained by higher flow events. Floods and floodplains are now viewed as essential components of fluvial (i.e., river) systems (Petts and Maddock, 1996).

Changes in the high flow component of the flow regime, such as limitation in the magnitude of high flow events, can have potentially profound effects on aquatic ecosystems (Resh et al., 1988; Gregory et al., 1991). This includes effects on the distribution, metabolism, feeding strategy, and behavior of organisms (Petts and Maddock, 1996). It can also include impacts on the long-term characteristics of aquatic habitats such as the quantity and quality of riffles and pools (Bjornn and Reiser, 1991; Everest et al., 1987; Lisle, 1982; Lisle and Hilton, 1992). Although the relationship between hydraulics, sediment transport, and ecological responses are complex and influenced by a variety of factors including land use patterns, these high flows remain an important determinant of the quality and quantity of fish habitat (Ligon et al., 1995; Kondolf and Wilcock, 1996).

Other factors at the watershed level that can impact aquatic resources are related to land use patterns. These factors can include the impacts associated with altered flow and sediment regimes due to forest practices, mining, agriculture, urbanization, and industrial processes. Often these land use practices work in interrelated manners to affect physical, chemical, and biological processes. For example, pesticide and herbicide practices can result in short term loadings from overland flow processes while contributing long term loadings through ground water interactions. Although the principal flow components described above present a rational basis for approaching instream flows, the more complicated interaction of point and non-point water quality constituent loadings, conjunctive ground water and surface water flows, and related land use activities must also be considered.

Conceptual Framework for Instream Flow Assessments

A problem-solving framework for the evaluation of ecologically based flow regimes for WRIA 1 is outlined in Figure 2. The framework is intended to conceptually organize specific technical elements that are required to address the physical, chemical, and biological processes that contribute to each component of the flow regime. The framework parallels the conceptual framework of the Instream Flow Incremental Methodology (IFIM, Stalnaker et al., 1995). It is not however, a direct implementation of the IFIM since several elements of the IFIM (e.g., legal and institutional analysis) are not considered as part of this effort.

The primary objective of this framework is the delineation and validation of each flow component at a spatial scale that incorporates the variability of landform, hydrology, land use practices, water quality, and other germane factors such as species distributions. The proposed framework relies on a process to identify the site-specific scope and need of instream flow assessment components and then the selection and application of appropriate component physical, chemical, and biological information. This process also includes identifying where the use of modeling is appropriate to understand and evaluate flow dependent conditions not necessarily observed through empirically based field observations. To aid in management decisions throughout the basin, the framework is intended to quantify these relationships in a manner that will permit inferences to specific locations where detailed site-specific analyses may not exist.

The framework is organized around nine major components:

1. Development of a Strategic Instream Flow Assessment Plan
2. Delineation of the Spatial Domain and Basin Stratification
3. Delineation of Strata (Site-specific) Assessment Needs
4. Delineation of Key Physical Processes by Strata
5. Delineation of Key Chemical Processes by Strata
6. Identification of Key Biological Processes by Strata
7. Development, Application, and Validation of an Integrated Assessment Framework
8. Development and Validation of an Instream Flow Extrapolation Methodology
9. Technology Transfer

A brief description of each of these components from the perspective of instream flow assessments is provided below in order to set the context for the specific technical approaches described later. Following this section, the report outlines detailed methodological approaches, data sampling protocols, analytical and modeling needs, and the process for validation and integration of these study components for evaluating instream flows. The choice of a specific technical approach is determined within the context of assessing instream flow objectives for specific locations within WRIA 1 under Component 3 above.

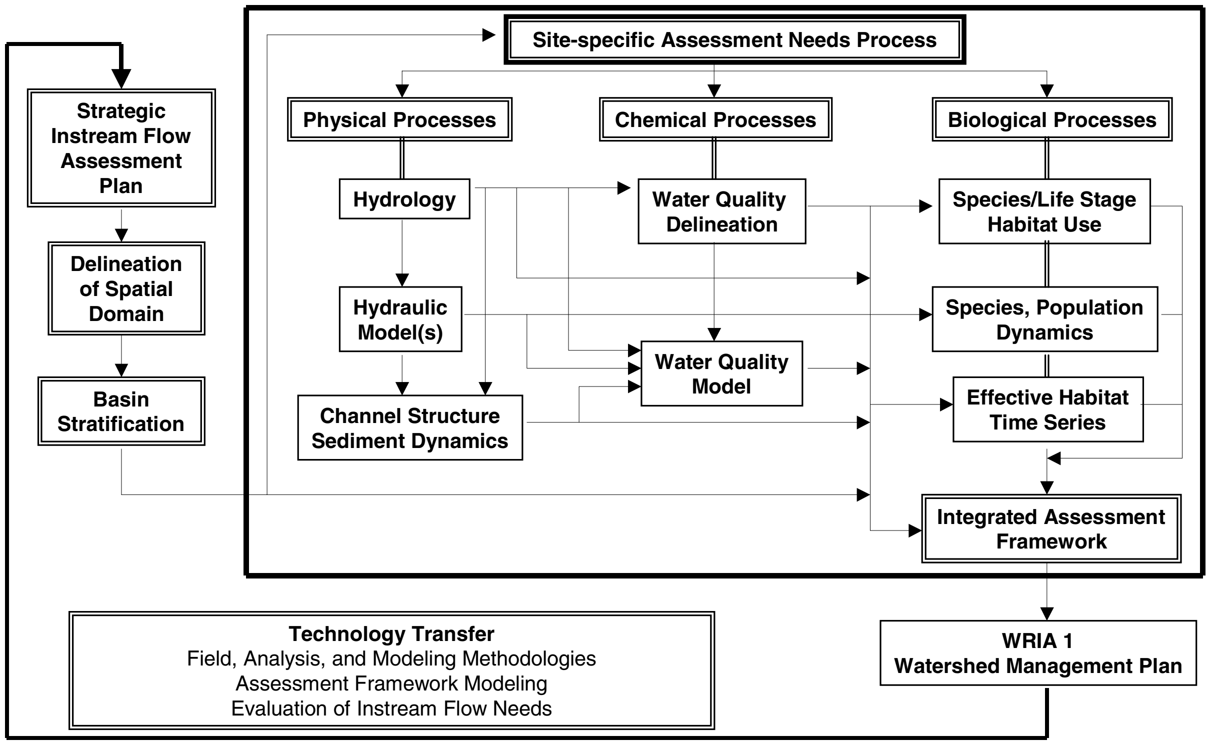


Figure 2. Conceptual framework and relationship between components for assessing instream flows.

Instream Flow Strategic Study Plan

A critical element of any program aimed at the assessment of instream flow needs for aquatic resources is the development of a strategic study plan. This strategic plan should identify known or suspected linkages between critical physical, chemical, and biological processes within a river basin in light of natural, historical, existing, and anticipated land use and water allocation practices. A strategic plan should also clearly identify linkages to other watershed planning efforts such as water quantity, water quality, and aquatic resource management objectives. It should clearly articulate the expected products for each study element and the methodological framework by which study results will be integrated for the purposes of assessing flow related allocation strategies in the decision process.

The strategic plan and specific technologies or modeling approaches must also be formulated in light of acceptable methodologies for specific study elements within existing legal and institutional programs (i.e., legal defensibility). The strategic plan can then be used as the basis for identifying specific technical approaches, resulting data requirements, development of integrated data collection strategies, specific modeling approaches, validation efforts, and methods for integrating and interpreting results.

Delineation of the Spatial Domain and Basin Stratification

Basin stratification should be used to implement the framework for instream flow assessments because it is the most pragmatic cost/benefit approach to meet both short term and strategic needs for watershed planning and management within WRIA 1. It is unreasonable to expect that the current effort can conduct a comprehensive intensive quantification of site-specific instream flow needs at every ‘critical’ location within WRIA 1. A comprehensive and systematic approach may require more than a decade and can cost in excess of tens of millions of dollars. In contrast, a stratification approach that focuses intensive data collection and modeling efforts at representative stream types in conjunction with key locations within WRIA 1 allows for the short term assessment of instream flows in a manner that can meet strategic objectives while allowing for ‘extrapolation’ of site-specific results to similar streams as a means of interim support to decision making.

The ability to implement both specific and generalized analyses necessary to support interim instream flow decisions where site-specific data may not be readily available within time constraints of legal or institutional frameworks is an important short term need for management agencies. A stratification approach however, does not preclude the need for, or the importance of, the evaluation of instream flow needs at specific locations given the importance of shorter-term legal, institutional, or political needs. In fact, these types of focused efforts, including the incorporation of available historical instream flow work, are an integral part of the recommended process. A stratification approach also focuses the initial assessment efforts on the development of an understanding of key physical, chemical, and biological processes in similar river systems or zones across the wide variability in system characteristics inherent in WRIA 1. In essence, the stratification approach relies upon the use of a Geographic Information System (GIS) to integrate the required multi-attribute spatial data in a systematic and rational manner. Stratification in this context attempts to organize the basin into groups of similar sub-basins or river reaches based on the expected similarities in physical, chemical, and biological components.

For example, small, high gradient, south facing, non-glacial tributaries in the North Fork can be expected to have similar characteristics in terms of hydrology, habitat types, temperature, invertebrate communities, fish, etc., as opposed to lower gradient or glacial dominated tributaries in the Middle Fork of the Nooksack River. Other efforts employing stratification of similar systems for the purpose evaluating resource states have shown this approach to be valid in representing flow dependent responses (e.g., RIVPACS III and HABSCORE). It should be noted that although the primary focus of this stratification process is oriented toward instream flows, the very nature of the accumulated data and reliance on a GIS approach allows re-stratification to meet alternative objectives within the broader context of watershed planning and management at any time.

Once a rational stratification process has been completed and validated, specific stream reaches within particular sub-basins of each stratum are then targeted for intensive study based on a combination of instream flow decision needs and a representative sampling of specific sub-basins covering the range of variability within a particular stratum (i.e., groupings of similar sub-basins or river reaches). The nature and extant of the approach to be taken for a given site and/or strata will be determined through the Assessment Needs process discussed in the next section. The quantification of flow dependent relationships between the physical, chemical, and biological processes can then be used to evaluate expected conditions and responses to proposed actions at sampled sites or for other locations within a specific stratum to aid in management decisions on instream flows in the absence of site specific data. An integral part of the framework and the application of the process is the collection of additional data at new sites to continually update and validate the predictive capabilities of the analysis system. This follows from the Adaptive Management principals that underlie the entire assessment framework and process of implementation. This process of delineating strata within a watershed, selection of representative stream reaches, and the subsequent evaluation of other stream segments within particular strata is illustrated in Figure 3.

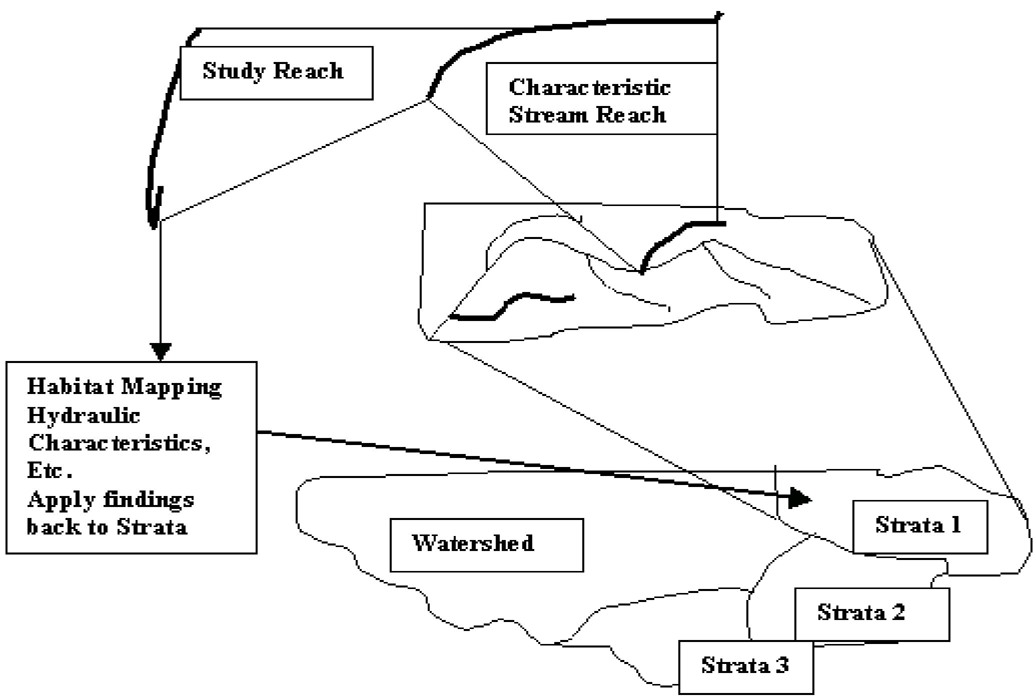


Figure 3. Conceptual relationship between strata, characteristic stream reach, study reach, and use of site-specific relationship to infer conditions to self-similar stream reaches in the same strata (courtesy of James Bucknell, Department of Ecology, Washington State).

Delineation of Strata (Site-specific) Assessment Needs

The delineation of the stie-specific study needs of each strata or component of the assessment framework is intended to develop a process to evaluate the specific instream flow and related questions that pertain to a particular site(s) within a given stratum. The focus of the process is to clearly identify the nature, need, scope, and complexity of the instream flow objectives. This evaluation should consider the spatial location, ecological, physical, and chemical issues that are identified within the context of other water related management objectives such as restoration efforts of anadromous species, and water rights. Once the instream flow assessment needs have been articulated, then the process should identify the appropriate data needs, analytical approaches, analysis tools, level of effort, and required work products necessary to address the identified instream flow assessment needs.

Delineation of Key Physical Processes

Typically, key physical processes required to assess instream flow needs are dominated by the interrelationship between hydrology, landform/channel structure and mesoscale habitat, sediment dynamics, and hydraulics. For convenience, temperature is addressed under chemical processes.

Hydrology

Detailed hydrology is needed to provide estimates of site-specific flow magnitudes, timing, duration, and frequency for various types of expected flow regimes (i.e., water year types). The evaluation of proposed instream flow regimes and fish population responses must consider the spatial and temporal variability in flow regimes. Hydrology is also required as input for the sediment, water quality, temperature, and aquatic habitat modeling requirements of the instream flow assessments. It is expected that the hydrology modeling by the USGS will meet the needs of the proposed instream flow assessment framework within WRIA 1 and therefore no specific technical approach is discussed for this element. Required output from the hydrology modeling identified by the Technical Team during the Instream Flow Methods Conference included monthly flow duration curves, flood frequencies, mean annual flow, and where feasible, flow time series.

Mesoscale Habitat Mapping

Mesoscale habitat mapping should focus data collection efforts within specific study reaches. Recognizable habitat types can then be linked to the physical habitat availability and to identifying biological responses at a broad spatial scale within the river reach. All river reaches or all available habitat types cannot feasibly be collected. Habitat mapping is a standard approach to focus the field sampling to ensure that the correct selection of study reach(s) and representative characterization of available habitats are obtained for use in instream flow assessments. The delineation of mesoscale habitats in the field is based on a river specific habitat classification scheme that incorporates the delineation of features in light of target aquatic resource needs. The following discussion is intended to help explain the role of habitat mapping and study reach selection in the instream flow process.

Study Reach

Once a particular river segment representing a characteristic stream type within a stratum has been identified for intensive investigations, the specific study reach or stream segment that will be sampled and modeled must be identified. This can be accomplished through a variety of approaches.

One approach identifies a specific study reach for sampling based on biological criteria. This approach is appropriate in a situation where it is possible to identify, through existing data, an area (or areas) of the river that is most sensitive to changes in flow, and/or is critical to the success of a particular species life stage. This is often referred to as a critical reach. If, for example, it is believed that the availability of spawning habitat is the strongest or most limiting factor to recruitment of a particular fish species, then the selection of a reach covering the known spawning area may be appropriate as part of a study designed to evaluate a flow regime that is optimal for recruitment of the species. Field efforts would then focus on the collection of requisite data in key habitat types within this critical reach.

If it is not possible to identify the critical dependency of a particular habitat type to a particular species/life stage as the limiting factor to success of the species, the relationship between the flow regime and the different habitat types present in the study reach may be determined by sampling the variability of all habitat types within the study reach. For a single species, different habitat types may be limiting to different life stages at different times of the year, and if the study addresses more than one target species, different habitat types may be limiting to life stages of different species. In either case, it is important that the study site(s) represents the full range of habitat types present in the larger length of river. The underlying process in this instance relies upon a habitat mapping approach. Specific habitat types to be sampled can then be identified through the use of a representative approach or by any number of random based selection methods of habitat units.

Habitat Mapping

Habitat mapping is one general approach to selecting the study sites and habitats to be sampled. Habitat mapping can be used to select study sites and habitats to be sampled as follows:

1: Within the study area in question, unique river reaches are identified as comprising different proportions of 'macrohabitat' types. Macrohabitat types can be defined by geomorphology and/or human influences such as channelization or diversion regimes. This may include river reaches where the stream hydrology is significantly different such as above or below tributary inflows or below a water diversion. Within each reach, the species assemblages are generally expected to be similar.

2: A classification scheme for delineation of specific mesohabitat types in the river, corresponding to basic habitat types (e.g., deep glide, shallow glide, pool, riffle, and cascade) is developed. This may be approached utilizing any number of different habitat classification schemes published in the open literature or adopted by resource management agencies involved with the study (e.g., Rosgen, 1984; Kershner and Snider, 1992, Hawkins et al., 1993). In addition to identifying different geomorphological features (e.g., pools and riffles), the distribution of areas having cover (e.g., overhead cover, undercut banks, or floating aquatic plants) and areas thought to be of special ecological importance (e.g., backwater refuges) should be identified where appropriate. The flows under which the habitat mapping fieldwork should be carried out must also be considered.

3: Habitat mapping is then carried out over an extensive longitudinal spatial scale to ensure that the overall characteristics of the river reach are adequately defined.

At the simplest level, the habitat mapping procedure may involve a visual assessment of the types of habitat present by walking the river reach in question. Clearly, the more homogeneous the stretch of river, the easier this task will become and it may be possible to represent the whole reach by a single representative reach containing replicates of all available habitat types. In some circumstances, such as in rivers with highly complex and variable habitat types, a more quantitative habitat mapping approach may be appropriate. One common approach is to delineate the number and linear distribution of each habitat type within the study sector using a predefined habitat classification scheme based on actual physical measurements. The investigator can then select specific habitats using representative reach(s) within the study area, or a stratified random selection procedure, or a combination of methods.

Another more detailed approach to habitat mapping involves the delineation of reaches of generally similar instream physical habitat identified through a survey which takes spot measurements of habitat variables such as stream width, maximum velocity, depth, substrate, and cover. Analysis of the distribution of these habitat variables can enable a detailed discrimination of habitat types. For example, it may highlight distinctive types of deep glides or pools. Based on these analyses, specific locations of study reaches can then be identified as outlined above. This approach, however, is more labor intensive and may not necessarily represent a more quantitative approach.

Still another variation on this basic theme for habitat mapping involves the random selection of a starting point within a specific study reach where habitat mapping is then conducted over a longitudinal distance equivalent to approximately 20-30 channel widths.

Based on the habitat types encountered, each habitat type is assigned as a stratum and the specific habitat unit within a stratum is randomly selected. The specific habitat unit(s) selected from each stratum is then determined using a random selection process. Although this approach is appealing from a strict statistical perspective, it typically requires additional cross sections being collected at hydraulic controls for each habitat unit selected and often selected habitat units may not necessarily be able to be sampled due to the physical constraints present within the river.

Although a variety of methods for the selection of reaches or specific habitat units have been discussed, it should be noted that no single 'preferred method' exists and the specific approach taken should be based on the objectives of the proposed effort. Furthermore, flexibility during implementation must be maintained given the realities of applied fieldwork and site-specific characteristics.

Hydraulic Characteristics

The purpose of hydraulic modeling is to characterize the physical attributes within the stream (i.e., depth, velocity, and substrate) over a desired range of discharges for available habitat types important to aquatic resources of interest. This characterization could be accomplished by direct empirical measurements over small increments of discharge that covered the range of discharges of interest for a study. However, time and money constraints typically prevent an empirical approach and we are forced to sample the stream hydraulics properties at a few target discharges. We then rely on these data to calibrate a hydraulic model(s) and use the model(s) to predict the stream hydraulic attributes over the full range of discharges of interest in our study. The success or failure of this effort is dependent on the quantity and quality of the field data, the physical complexity of the stream, and ultimately the ability of hydraulic models to reflect the physical processes in the stream.

The delineation of hydraulic characteristics of the flow regime (i.e., depth and velocity) at specific locations is necessary to quantify the physical habitat structure of a stream or river and is required to evaluate the flow dependent characteristics within the study reach. The specific goal is to define the characteristics of substrate, depths, and velocities, within specific mesoscale habitat units representative of homogeneous river reaches. These data will provide the base information for several elements of the flow assessments including fish habitat availability versus flow, and integration of sediment transport analysis, water quality, and habitat/riparian habitat maintenance flow considerations. In particular, detailed spatial representations of habitat combined with observed fish distributions are essential in determining/validating habitat use of fish at different flows in a particular study site or habitat unit. These data are also used to quantify large and small-scale sediment transport processes related to maintaining habitat features (e.g., backwaters) and overbank floodplain and riparian processes related to flow magnitude and frequency at each study site. When tied to coarser whole river habitat mapping, the habitat unit specific data can be accurately extrapolated to the entire river reach of interest.

Historically, hydraulic characterizations utilized for simulations of fish habitat relied on a variety of 1-dimensional hydraulic simulation routines based on cross section data of the river geometry, water surface elevations at different discharges, and observed velocities to calibrate these models (e.g., the Physical Habitat Simulation System "PHABSIM"; Hardy, 1998a). The calibrated hydraulic models are then used to simulate the hydraulic attributes of depth and velocity over a user specified range of discharges. However, the application of the one-dimensional hydraulic models often obtains a simplified picture of the actual hydraulics, which is not always considered sufficient (Ghanem et al., 1996). In particular, this approach often calculates velocities at a cross section by dividing the river into independent cells and then solves Manning's equation in terms of velocity for each cell for a specified discharge. The calibrated Manning's n value at each cell (or vertical) is most often determined from a single set of measured velocities across each cross section. When modeling a river with cross sections that may be anywhere from ten feet to many hundreds of feet apart, detailed velocity information throughout the spatial domain within the channel cannot be obtained. Although selecting a large number of cross sections over very small areas (i.e., a few feet) will likely improve velocity prediction capabilities, use of one-dimensional hydraulics is still limited in its ability to accurately predict flow about complex channel geometries which have significant two and three dimensional characteristics. Additionally, the cost and time constraints in operational instream flow studies typically preclude collection of cross sections at this level of measurement scale. Recently, because of the advances in the capabilities of computers, models for two- and three-dimensional hydraulics are becoming more widely available and applied within the area of instream flow assessments (Leclerc et al., 1995; companion articles in those proceedings).

Recent advances in GPS, soft copy photogrammetry, hydroacoustics topographic mapping, and Acoustic Doppler Current Profiling (ADCP) technologies have now made collection of highly accurate 3-dimensional channel topographies possible. Below water surface channel topography can be collected using a survey grade GPS (ca. 1 cm accuracy) coupled with hydroacoustics. Above water or shallow water portions of the channel topography can be collected with a combination of GPS, conventional laser level surveys, and low level photogrammetry (aerial stereo pairs). By combining the below water GPS-hydroacoustics data with the shallow water and above water survey data, a complete and accurate representation of the channel topography can be generated along with the water depths at the discharge observed during data collection. Velocities throughout the study reach (or habitat unit) at the observed discharge can be obtained by using a combination of conventional velocity meter measurements and ADCP technologies. These data are suitable for use in a variety of 1-d and 2/3-d hydraulic models. Care must be taken during the data collection phase to ensure that the channel topography is accurate and detailed enough to allow these flow models to accurately model velocities and to ensure that the selected hydraulic model is calibrated properly. To calibrate the flow model to the observed flow, an accurate water surface profile along the study reach must be obtained and the spatial distribution of velocities and substrates (roughness) obtained.

Accurate representations of substrate can be obtained using conventional mapping techniques or potentially extracted from the acoustic profiling data. Longitudinal water surface profiles can be accurately obtained using conventional Total Station survey equipment or survey grade GPS equipment.

The most important aspect of being able to use the above data to determine hydraulic characteristics at flows higher and lower than those observed during the data collection (i.e., for flow regime analysis) is the collection of calibration data at higher and lower flows. Longitudinal water surface elevations throughout study reaches (and specific habitat units sampled), at a minimum of three widely spaced flows, is necessary to ensure the best opportunity for flow model calibration and validation. A stage discharge relationship is also needed to establish the downstream boundary condition for 2- and 3-dimensional models. Additionally, measurements of velocity at alternative flows are needed to validate the accuracy of the modeling and generate confidence bounds for the data.

Channel Structure, Sediment Dynamics, and Riparian Habitat

The relationships between flow dependent characteristics and the channel structure, sediment dynamics, and riparian habitat are critical for the proper evaluation of all components of an instream flow regime. This effort should be focused on the specific evaluation of the flow regime to either maintain the existing channel form, local scale habitat units, and riparian community or where deemed appropriate, create needed changes in these conditions.

Alluvial streams create their own geometry. They create an equilibrium channel form given the constraints of topography, geology, and vegetation, that allows the stream to pass the water and sediment supplied from upstream (Leopold et al., 1964). The channel form is directly related to sediment transport (both the sizes and amounts of sediment moved). Sediment transport is a function of sediment supply and the magnitude and frequency of water flows. The sediment that is most important in terms of channel geometry is the sediment that makes up the bed and banks of the channel (Gomez, 1991). Typically, depending on the river, the material is relatively coarse particles (large sand, gravel, and cobble). This coarse material is primarily transported as bedload (i.e., rolling, sliding, or saltating along the channel bottom), and as a result bedload transport ultimately determines the gross morphology of the stream. Finer sediments that are mostly transported in suspension at higher flows, while perhaps not a major determinate in the gross morphology (depending on the river), can control micro channel morphology through local deposition in backwater areas, in pools at low flows, and in the upper layer of gravels and cobbles. These finer sediments can also be deposited in slow water areas created by vegetation that has established in the channel or in vegetation along the margins of the channel and cause local areas of channel aggradation (Friedman et al., 1997). In addition, these fine sediments are deposited on the floodplains and affect the form and function of the floodplain. Detailed measurement and modeling of 3-dimensional flow and sediment transport process can help in the understanding of smaller scale bedform and habitat unit processes that generate channel habitat features (e.g., backwaters) critically important to many life stages of fish and other aquatic species. These models require detailed geometry data, but provide the ability to model changes in topography in response to varied flows (e.g., Andrews and Nelson, 1989).

Research has shown that the channel geometry or bankfull channel size is directly related to effective discharge (e.g., Wolman and Miller, 1960). Bankfull flow is the flow that just overtops the active floodplain (relatively flat depositional zone along the margins of the stream). Effective discharge is the discharge or range of discharges that over time move the most sediment in the channel. Effective discharge in streams can be determined by either modeling or measuring the bedload (and suspended) sediment transport and combining this relationship with the site-specific frequency and magnitude of the flows. Research to date has shown a nearly 1:1 correspondence between computed effective discharge and actual bankfull discharge (e.g., Andrews, 1980: Andrews and Nankervis, 1995; Batalla and Sala, 1995; Franseen and Pitlick,1997). The effective discharge, or bankfull discharge, typically has a recurrence interval of approximately 1.5 years (Leopold et al. 1964), but higher and lower recurrence intervals have been observed. Alterations to the effective discharge in a stream over time as a result of natural or anthropogenic changes in flow or sediment input can be expected to result in concordant changes in channel size.

Identification of flow regimes that maintain both the health and vigor of established riparian vegetation and the process of regeneration and reproduction of riparian species is in its infancy. Relatively recent research results in arid and semi-arid regions, however, have identified some of the important relationships and processes that occur. Most of these are related to the timing and availability of soil moisture (e.g., Hupp and Osterkamp 1996) and to channel scour and deposition processes (e.g., Scott et al., 1996). Establishment of vegetation frequently requires high flows that create bare, moist soils and maintain summer ground water levels (Stromberg et al., 1991; Stromberg, 1993). Maintenance of mature vegetation requires maintenance of base ground water levels and floodplain deposit moisture levels (Stromberg and Patten, 1990; Stromberg, 1993; Stromberg and Patten, 1996). Riparian species richness and diversity is frequently maintained by intermediate levels of floodplain inundation (Stromberg, 1993; Pollock et al., 1998). Riparian vegetation also impacts the channel processes upon which it is dependent. For example, riparian vegetation can protect the integrity of channel banks and reduce scour and it can reduce soil moisture.

The specific technical approach(s) to measure and/or model flow, sediment processes, and riparian flow needs is dictated by the nature of the site-specific characteristics of the vegetation community, sediment supply, and flow regime. For example, simplified methods are likely to be adequate in supply limited high elevation non-glacial streams, while more empirically based physical modeling approaches are likely to be required in other areas affected by high sediment loadings or in glacial dominated systems.

Delineation of Key Chemical Processes

The importance of chemical processes to aquatic resources is well known and many key biological processes for aquatic resources are directly linked to such factors as temperature, dissolved oxygen, nutrients, organic and inorganic contaminates, toxic metals, etc. Given the complexity and heterogeneity of these factors within WRIA 1, the current effort should be focused on a combination of simplified and intensive approaches tied to the site-specific character of study reaches.

Two of the more important factors for aquatic organisms are related to the flow dependent relationships between temperature and dissolved oxygen. These two factors govern maturation and growth for all life stages of aquatic organisms and in the extreme can result in either chronic or acute effects that may limit populations. The interrelationship between the seasonal flow regime and its thermal characteristics can also affect the timing of upstream and downstream migration of anadromous species. Nutrient dynamics directly affect primary productivity and in turn affect secondary productivity upon which many fish species and life stages are dependent for their food. Excessive nutrients can lead to excessive algal production and deleteriously affect dissolved oxygen dynamics. Organic loadings, especially in the form of municipal, industrial, and agricultural waste byproducts, can result in both direct and indirect impacts to aquatic resources including human health hazards. Chronic and acute exposure to other water quality constituents such as heavy metals, pesticides, and herbicides have also been documented to affect aquatic resource metabolism, behavior, and community structure.

Although numerous water quality modeling tools are available and capable of simulating riverine conservative and non-conservative constituents, the biggest limitation is typically in the availability of suitable data sets for model calibration and validation. The primary focus of the chemical processes component within the assessment framework should be to concentrate on temperature and dissolved oxygen dynamics. However, in locations where other water quality parameters have been identified, additional constituents such as BOD, nitrates, etc, will need to be included. This effort will also involve the determination of the constituent loadings such as point loads versus non-point loadings where necessary.

Identification of Key Biological Processes

The primary focus of the biological processes component is an empirical based assessment of physical habitat quantity and quality and related energetic based metrics for fish to different flow regimes and seasonal changes in temperature and water quality.

Presently, the Instream Flow Incremental Methodology (IFIM) is the most widely applied method of assessing the instream flow needs of aquatic resources (Reiser et al., 1989; Hardy, 1998b). Within the problem-solving framework of IFIM, the Physical Habitat

Simulation system (PHABSIM) is the most commonly applied set of analysis tools to examine flow dependent needs of aquatic resources. PHABSIM is, as the name suggests, a body of simulation tools that allow an investigator to evaluate flow dependent physical habitat quantity and quality for species and life stages of interest. This type of approach is sufficient when the target species and appropriate life stages have adequately defined habitat preferences; the bathymetric, hydraulic, and hydrologic characteristics of the system are accurately measured or simulated; and physical habitat quantity and/or quality is an important determinant (Hardy, 1998b). Numerous authors have demonstrated the utility of this basic approach ([Jowett, 1992; Jager et al., 1993; Nehring and Anderson, 1993; Railsback et al., 1993; Bovee et al., 1994] in Hardy, 1998b).

In spite of the widespread application of PHABSIM, the approach has received criticism ([Orth and Maughan, 1982; Mathur et al., 1985; Shirvell, 1986; Scott and Shirvell, 1987] in Hardy, 1998b). Some of these criticisms however, are based on testing assumptions that are unrealistic or several steps removed from the direct link (e.g., assumptions that fish populations respond directly and instantaneously to flow (Mathur et al., 1985; Scott and Shirvell, 1987)). In particular, the empirically based habitat models presently used have been criticized for lack of biological realism (Orth and Maughan 1982) and for lack of correlation to growth or production potential. This criticism is largely directed at the reliance on empirical habitat suitability curves. Numerous researchers have proposed bioenergetically-based approaches of various forms in an attempt to better link habitat models and the governing biological mechanisms (Fausch, 1984; Beecher, 1987; Hill and Grossman, 1993; Hughes, 1992; Addley, 1993; and Hayes, 1996). These models essentially attempt to quantify Net Energy Intake (NEI) as the energy assimilated through feeding minus the energy expended through basal metabolism and swimming cost for each size and species of fish in a given physical habitat. These models assume that NEI is the primary factor in feeding habitat selection by salmonids although deviations from NEI predictions may result from the influence of competition, predation, cover seeking, or other factors.

Bioenergetic modeling offers a number of potential advantages over the empirical correlations commonly used in the development of habitat suitability criteria. First, bioenergetically-based models incorporate the mechanisms through which physical and biological processes interact. These mechanisms then provide a foundation for inferring causation in observed phenomena. Second, a mechanistic approach is theoretically more universally applicable, and is therefore transferable to other river systems. Third, since bioenergetic modeling is based on net energy intake by resident organisms, it is inherently linked to growth rate, size potential, and biomass production. Last, an energetically based approach offers better opportunities for linkages to watershed scale ecosystem processes such as forest production, temperature, nutrient inputs, and watershed condition. Bioenergetic approaches have also been used to estimate predator impact on prey populations, model bioaccumulation of toxins, and forecasting the fate of introduced species (Ney, 1993). Bioenergetically-based models can be used to determine (1) velocity and depth preferences, which are equivalent to habitat selection as commonly evaluated with habitat suitability criteria used in PHABSIM (Addley, 1993; Ludlow, 1998; Hill and Grossman, 1993; Hughes and Dill, 1990; Hughes, 1992; Hayes, 1996; Baker and Coon, 1997); (2) estimates of growth potential (Fausch, 1984; Hughes, 1998); or (3) the growth component of a larger modeling framework that includes population level attributes (Van Winkle et. al., 1993). Each of these applications can be viewed as a step in the progressive evolution of a bioenergetic based approach.

Development, Application, and Validation of an Integrated Assessment Framework

Quantification of the component processes described above requires an integrated assessment framework (see Figure 2). Basin specific modeling and analysis frameworks have become increasingly important in watershed management and planning efforts throughout the past decade and represent the current trend in watershed planning and management (e.g., SIAM, WBDSS; Flug et al., 1999, UWRL, 1998). These assessment frameworks permit interested parties common access to key decision variables, allowing the evaluation of alternative flow scenarios or proposed management activities without the need to master all the underlying technical components. These frameworks are also commonly developed from the perspective of a decision support system with linkages to updateable data archives that support the various technical modeling components and are modular in that different technical models can be used to meet specific purposes with minimal or no changes to the system structure.

Development of such a system for WRIA 1 is largely inherent in the GIS-based approach to stratification and should allow for easy direct linkage to the water quantity modeling efforts currently underway by the USGS. Additional efforts would require integration of water quality, temperature, and habitat models for target stream segments and the supporting database components for data archiving. The validation of specific modeling components such as water quantity, water quality, and temperature, and aquatic resource models are initially achieved during the development and testing of the specific components. Validation of the integrated assessment framework should then be undertaken through field sampling of key system indices (e.g., temperature, fish use, etc.) as part of on-going monitoring activities or through specific efforts focused at this element. This final step minimizes the uncertainty in the decision process in evaluating proposed actions and where unacceptable modeling results (component or aggregate) are identified, it allows corrective actions to be focused for on-going strategic efforts. This type of assessment framework is also ideally suited to address the issue of cumulative impact assessments for specific target resources since its underlying structure is spatially oriented.

Development/Validation of Instream Flow Extrapolation Methodology

One of the principal purposes of the stratification and assessment framework is to provide decision makers access to information at a screening or reconnaissance level for evaluating proposed actions at locations where site-specific data do not exist. The generalized relationships developed for specific stratum can be used to evaluate the expected response in key system variables to assess the likely ‘impact’ of a specific activity. In the event that a proposed action is likely to have significant impacts, the initiation of site-specific studies may be warranted to aid the decision process. New data and analyses would then be integrated into the framework and the generalized relationships updated in an on-going manner. The development of an extrapolation methodology entails the generalization of site-specific modeling results for each stratum. The implicit assumption is that other similar streams contained within a particular stratum should respond in a similar fashion. This can be validated by collection of additional site-specific data of key system response variables (i.e., temperature, water quality, fish habitat, etc.) and compared to the generalized response based predictions. Where some strata may have a higher variability and the reliability of modeling results are in question, additional site-specific data can be targeted for collection and the generalized extrapolation procedures can be updated.

Technology Transfer

The primary goal of the technology transfer component of the assessment framework is to ensure that long-term expertise capable of implementing any specific technical component or the utilization of the assessment framework will be available within WRIA 1. This represents a critical investment for all concerned parties since confidence in the technical underpinnings and evaluation of proposed activities is central to the decision process in watershed planning and management.

Technology transfer will also be important in terms of the long-term need to incorporate new data, revised understanding of specific processes, or to make adjustments to accommodate new technical elements. The principal technical elements of technology transfer that should be addressed include:

- Implementation of specific field sampling methodologies for all components
- Application of modeling tools, including calibration and simulation
- Verification and validation of modeling components
- Methods for integration of technical elements and their interpretation
- Updating and utilization of the assessment framework

A strong collaborative program should be put in place for all aspects of field collection, data analysis, modeling, and integration of study results. This is a critical element in the development of the overall framework to ensure that all participants have a working knowledge of the methods, assumptions, data, analyses, and interpretation. This understanding fosters an open, unbiased knowledge base upon which the evaluation of flow regimes or proposed management actions can be made in light of specific objectives of the management agencies and other stakeholders.

Detailed Description of Technical Approaches for Specific Study Elements within the Assessment Framework

The following sections detail recommended technical approaches for each of the proposed study components. This includes the specific recommended methodological approaches, data requirements, analysis and modeling approaches, validation steps, and linkages between the study components. The recommended approach is rationally based, quantitatively sound, and systematic based on currently recognized instream flow methodologies. It is based on a robust balance between data breadth and detail and includes the consideration of time and cost requirements in light of the variability and spatial extent of WRIA 1. In particular, the recommended approach focused on identifying a rigorous method to data collection, processing, analysis, and modeling that will produce a scientifically defensible product. The recommended approach also stresses the importance of validation for all study components.

I. Strategic Instream Flow Assessment Plan

Task I.1 Develop Assessment Plan

The assessment plan development task will focus on an evaluation of the known or anticipated instream flow related issues throughout WRIA 1. In particular, the plan should address the assessment of high priority instream flow questions that incorporate other water planning needs such as the anadromous species restoration efforts. This would include the identification of stream reaches with known physical, chemical, and biological related issues and setting initial priorities for implementation of related study components. The assessment plan should also address an evaluation framework that can be used to identify site-specific instream flow issues such that specific data and analysis methods are identified for application. This strategic assessment plan should also consider issues of how specific results generated will be interpreted and utilized within the broader watershed planning effort.

II. Stratification

Task II.1 Collate Data Layers and Development of GIS Structure

The initial stratification task should focus on the integration of available data layers that are both important to the analysis for stratification of WRIA 1 into similar stream types but also serves as the integrating tool for linkages to other key watershed level data, modeling, and analyses. From an instream flow perspective, the Salmonid and Steelhead Habitat Inventory Assessment Project (SSHIAP) system already contains many of the key spatially distributed characterizations of the stream reaches within the WRIA 1 while additional data exists from efforts by other state, tribal, and federal management agencies. Table 1 identifies some important physical, chemical, and biological components that were identified during the Instream Flow Workshop as key data layers to be considered in the stratification analysis but is not necessarily comprehensive. In the event that areas within WRIA 1 are lacking key data elements identified within Table 1, then specific efforts to acquire these data should be implemented.

Table 1. Data layers for consideration in the stratification of similar river reaches.

Species and Life Stages:
  Distribution, Timing, Composition, Status, Abundance, and Barriers
Vegetation:
  Age, Composition, Condition, Riparian Presence/Absence, and Stability Index
Land Use:
  Permeability, Land Use Classifications
Basin Characteristics:
  Size, Aspect, Slope, Elevation, Surficial Geology, Soil Types,
  Relief, Drainage Density, Valley Type, Basin Shape, Channel Form
Water Quality:
  303(d) Classification, Point/Non-Point Loadings, and Sediment Regime
Hydrology:
  Precipitation, Relief, Water Source (e.g., glacial vs. snowmelt)

Task II.2 Development and Implementation of Standardized Nomenclature

The second stratification task should focus on standardizing nomenclature for each of the identified data elements in Table 1. This effort will be required due to the variability in data source nomenclature such as SSHIAP versus the Forest Service stream classification system used on river reach inventories. Collaborating parties should derive a single consistent nomenclature for each data component, including standardized methodologies to guide future work. Once a consistent nomenclature has been established, specific data sources will need to be revised to conform to the selected nomenclature for the various data layers prior to stratification analyses.

Task II.3 Stratification and Validation

The stratification and validation task implements the actual stratification procedure to identify similar river types within the basin. The specific analytical approach taken should consider a hierarchical approach and to some degree will be dependent on the experience and preferences of the investigator. Validation of the stratification procedure should be undertaken and involve acquisition of ground truth data of key data types from a range of stream systems. These independent data should then be used to assess the predictive capability of the stratification process to correctly classify stream segments into the appropriate strata. Based on discussions with knowledgeable resource managers and site reconnaissance throughout the basin, it is anticipated that approximately 10-15 strata will be identified in the stratification analysis.

Task II.4 Selection of Similar Rivers for Intensive Investigation

Once the stratification procedure has been implemented and validated, three similar river segments within each stratum should be targeted for intensive site-specific characterizations. Specific rivers and tributaries targeted for intensive investigations should follow a random selection process unless site-specific instream flow assessment needs within a particular stratum require selection of a specific site to meet goals of the management agencies. Unless overridden by instream assessment needs, degraded systems should be avoided in the selection of intensive study sites within each stratum. Where existing site-specific data have already been collected and analyzed, these sites within particular strata could be utilized (updated with requisite data needs) or used in the validation step.

III. Site-Specific Physical Characterization

At each selected river within particular strata, the following tasks are required for physical characterization of the river for use in the instream flow assessment process.

Task III.1 Site-Specific Ground Based Habitat Mapping

The site-specific habitat mapping focuses on the acquisition of ground based habitat delineations using a standardized classification system to determine the type, distribution, and amount of specific habitat types within the river reach. Each habitat type should be delineated in terms of its length and average width. In those instances where selected river systems are of moderate to large scale (i.e., average widths ~ $\geq$ 50 feet), the habitat typing can be accomplished through the use of aerial photographs if available. For smaller systems the habitat mapping is more readily accomplished by ground based surveys. This may be accomplished with the use of hip chain, laser range finder, survey tape, or GPS.

It is strongly recommended that in all but the most unusual of cases, the entire river segment should be habitat mapped. In those instances where the river is too small to be effectively typed from existing aerial photographs and of excessive length, then at least several miles should be mapped rather than confining the mapping to some fixed length as a proportion of channel width.

Task III.2 Selection of Intensive Study Site

Based on the habitat mapping under Task III.1, the specific reach boundaries where intensive data collection will be collected should be determined. As noted in the discussions above, this may be approached from the perspective of a critical reach where important biological considerations may require a focused spatial effort. If a critical reach is selected, the reach length should be extended to ensure that replicates of all available habitat types are represented within the study area.

In some instances, extremely rare habitat types that are of marginal benefits to the community of target aquatic resources may be dropped from further consideration or be included if they represent a critical feature to the needs of the resources. For example, a specific riffle may represent the critical passage location to spawning or rearing habitats further upstream within a tributary. In this instance, sampling efforts may be concentrated in the upstream reach, while a focused effort at the riffle may be warranted. In many instream flow studies, habitats that represent less than some pre-defined proportion of the total habitat availability (e.g., less than 10 percent) may not be targeted for inclusion in further work. This should be carefully considered in light of the potential importance of these habitats to all members of the aquatic community prior to exclusion.

In the absence of the need to establish a sampling site from a critical reach perspective, it is recommended that a representative reach approach be used. The reach should be selected based on the habitat mapping results such that at least two and preferably three replicates of all available habitat types are represented within the longitudinal extent of the study reach. Where multiple, potential representative reaches may exist within a river segment, factors such as site access should be considered in the selection process. Once the study segment has been selected, permanent upstream and downstream survey control points should be established and these control points tied to known horizontal and vertical survey controls. This may be accomplished with survey grade GPS units or standard survey methods. These survey controls also represent redundant benchmarks for use in all subsequent field survey efforts where known elevation and positional data are needed. Therefore, these control points should be established in the upland zone well above the upper elevation extent of the riparian zone to minimize loss during high water events.

Task III.3 Establish Hydraulic Control Locations

Once the longitudinal extent of the study reach has been determined, downstream and upstream hydraulic controls should be selected to represent the area where the hydraulic and other data will be collected. This is critical for hydraulic modeling needs as well as for aiding in the biological validation work covered under other tasks. At each of these hydraulic controls, a cross section should be established which is perpendicular to the axis of the river flow and permanently marked on both sides of the riverbank. The position of these markers (i.e., head pins) should be established at an elevation that is clearly in the upland vegetation zone. These head pins can also be used as the survey control to mark the upper and lower bounds of the study segment referenced under Task III.2. A continuous temperature data probe should be established at each site.

Task III.4 Delineation of the Channel Topography and Hydraulic Properties

The delineation of the channel topography and related hydraulic properties will be dictated by the size and characteristics of the river segment being studied. Therefore, the following three sections of this technical task are broken out by segment characteristics.

Task III.4a Small High Gradient Systems (Channel Widths < 75 feet)

In small high gradient systems (channel width < 75 feet) the most effective sampling strategy involves characterization of the channel topographies and hydraulic attributes utilizing cross sections in non-super critical areas (i.e., pools). These areas are typically associated with high value aquatic resource areas while the highly turbulent (i.e., cascade/fall) portions of the stream are difficult to model although important to many aquatic resources such as macroinvertebrates. At least three cross sections should be located in each pool (start, deepest, and tail out) and placed to represent the variability of lower gradient habitat units (i.e., runs). It is recommended that at least three replicates of each habitat unit should be sampled. Selection of the specific units can be undertaken using a random selection process or professional judgment based on access and sampling logistics. For each cross section, permanent head pins should be located at an elevation above the riparian vegetation zone within the channel and the cross section should be oriented perpendicular to the main access of the flow within the channel. Cascade and falls can be barriers or flow-dependent barriers. To evaluate if or when they are barriers, water surface elevations above and below the feature should be measured and modeled. Velocity profiles at the bases of notches and other critical points should also be measured and modeled.

At each cross section, the channel bed elevation should be measured at a fine enough horizontal spacing to ensure that a detailed topography can be obtained. Typically horizontal spacing should occur at major changes in the channel topography or substrate type and spacing should not exceed a distance through which more than about 5 percent of the flow would occur. At each vertical (i.e., at a horizontal distance across the stream), the depth, mean column velocity, substrate, and cover data should be collected. During field data collection at all flows, the lateral and longitudinal extent of the plunging flow plume should also be quantified relative to the plan form dimensions of pool habitats. Substrate characterizations should follow the standardized classification scheme adopted within the State of Washington for use in instream flow assessments. In addition, when collecting the channel bed elevations, the start and stop of riparian vegetation by major community type should also be noted. Collection of mean column velocities should occur at least for target intermediate and low flows. Water surface elevations should be collected at a minimum of three discharges representing a high, medium, and low flow. These target discharges can roughly be selected to represent the flows associated with approximately the 20, 50, and 80 percent annual flow exceedance values respectively. Where definable bank full flood plain surfaces are evident within the study reach, these surfaces should be noted and these surfaces surveyed over the entire longitudinal profile of the study reach. Concurrent with these measurements, the longitudinal profile of the water surface elevation at each measured discharge should also be completed, where all major breaks in the water surface profile are measured. Wolman pebble counts should be collected in a riffle or other suitable habitat type following established guidelines (Wolman, 1954).

Task III.4b Small Lower Gradient Systems (Channel Widths < 75 feet)

Collection of channel topographies and associated hydraulic properties for small lower gradient systems (channel widths < 75 feet) should generally follow the guidelines suggested under II.4a with the following modifications. In these systems, three cross sections should be used for pool habitats, while one to three transects can be used for other habitat types depending on their relative heterogeneity. Placement of cross sections within key habitats can also be associated spatially with known spawning redds or documented rearing habitats. Again, at least three replicates of each habitat type should be targeted for sampling. In these systems, Wolman pebble counts should be collected at a riffle or at a crossing bar following established guidelines.

Task III.4a/b-1: Hydraulic Data Reduction

The hydraulic data reduction task will involve the data reduction for cross section based field data collections. Transfer of all field measurements to suitable electronic format should follow standard QA/QC procedures, discharges for all cross sections as well as the best estimate of the discharge should be computed, and the left, right, and average water surface elevations should be computed for each cross section. These data, in conjunction with the bed elevations, should then be used to generate cross section profile plots with the observed water surface elevations for all calibration data, plots of the velocity profiles for all velocity calibration sets, and the distribution of substrate/cover coding for each cross section. The longitudinal profiles of the calibration water surface elevations and the observed relationships between stage and discharge for all cross sections should be generated to aid in hydraulic model calibration. These data will serve as input to 1-dimensional hydraulic models (e.g., PHABSIM).

Task III.4c Moderate to Large Systems (Channel Widths > 75 feet)

The nature of moderate to large systems (channel widths > 75 feet) allows for an alternative approach to the field data collection and subsequent analysis methods. In these instances a combination of low elevation high-resolution aerial photogrammetry and acoustic based mapping of the channel topography is the most cost-effective approach. The technical steps in implementing these approaches are described below.

Task III.4c-1: Establishment of Control Network for Aerial Photogrammetry

The procedure for implementing a GPS control network consists of establishing three to four control points that are placed along the study reach. Points are placed in a non-linear alignment so that triangulations between points can be carried out to rectify coordinate positions. This is done by installing permanent survey markers that are located using survey grade GPS equipment or with standard survey techniques from known horizontal and vertical control points. When using GPS, data are collected on each point for times varying from twenty minutes to ten hours depending on satellite configuration and previously established control points that are located in the study area. Once a GPS control network is established, future surveys can use these points as controls.

Task III.4c-2: Image Acquisition

Acquisition of low elevation high-resolution imagery should be targeted for the time period associated with the lowest practical flow within the channel to maximize the exposure of channel topographies. The photogrammetry derived digital terrain models (DTMs) can be expected to have accuracies in the x, y, and z directions of approximately 1/10,000 of the flying elevation. Anticipated accuracy requirements should be in the range of 0.1-0.2 ft and, therefore, flying elevations to be 1,000 to 2,000 ft. Images will have a scale of from 1/2000 to 1/4000 and a footprint of 1,500 to 3,000 feet. If greater accuracy is required, DTMs can feasibly be generated with an accuracy of approximately 0.03 feet. Accurate and well-dispersed survey control points that are visible in the aerial photographs are necessary to generate the DTMs. Topographies that may be obscured by riparian vegetation should be delineated (i.e., horizontal and vertical measurements) using standard survey techniques, GPS, laser level, or other suitable sampling equiptment. Sampling in these areas can be approached using a systematic irregular sampling strategy that focuses on delineating changes in the plan form topography. Substrate characterizations should also be made for above water topographies by delineating polygons with GPS. Concurrently, a discharge estimate and the longitudinal profile of the water surface elevation should also be collected.

Task III.4c-3: Hydroacoustic Based Mapping of Within Water Channel Topographies

The hydroacoustic based mapping of the subsurface channel topography (i.e., under water topography) should be collected with a minimum target spatial sampling density of 3-5 feet. It should also be augmented with finer detail data where channel complexity is high. Greater or lesser target spatial resolutions may be dictated by the relative complexity in channel topographies. Hydroacoustic mapping should be conducted at a discharge that is greater than the discharge at which the aerial photogrammetry was collected to ensure an overlap between these data sets and to minimize the potential for missing topographies where the acoustic mapping is limited by water depths at the stream margins.

The longitudinal profile of the water surface elevations over the entire study reach should be measured at a minimum of three discharges and tied directly to the upstream and downstream control cross sections. These water surface profiles should also be accompanied by an estimate of the discharge for the reach. Velocity measurements throughout the study site should be collected at three different discharges to quantify the accuracy of the flow models. During the initial delineation of the channel topographies, the concurrent collection of ADCP 3-dimensional channel velocities should also be undertaken. These data should be directly linked to the GPS integrated bottom profiling data stream. In addition, at the other target discharges where water surface elevation and discharge data are collected, spot sampling of the velocity profiles in representative areas of heterogeneous velocity fields within the study reach should be collected to aid hydraulic model validation.

Task III.4c-4: Aerial Photogrammetry Data Reduction

The aerial photogrammetry data reduction task involves the reduction of the low elevation high-resolution aerial photogrammetry data collected from an intensive study site. The first step involves the data reduction and QA/QC of the survey control networks collected at each site. This step is required to associate horizontal and vertical control points to specific target locations in the stereo imagery in order to process the stereo pairs for digital terrain modeling. The second step requires the scanning of all the stereo photographs into digital format, completing the interior and external orientation of the aerial photographs, generation of complete site bundle adjustments, and generation of individual stereo pairs for each site. The final step is the development of the actual three-dimensional topographies at each site for all above water topography and generation of a digital orthophotograph map.

Task III.4c-5: Hydro-acoustic Data Reduction

The hydro-acoustic data reduction task requires two steps. The first step involves the basic data reduction, censoring, and QA/QC of the raw field data. This effort removes any suspect data points where either bottom lock was lost on the acoustic profiling gear or GPS location data are outside established error bounds. In addition, the data are screened for outliers where shallow water interference relative to boat speed may result in time-delayed errors in the location data. The second step utilizes the processed data from the previous step and the integration of the longitudinal profile of the survey data of the water surface elevations and depth readings in order to generate a bed elevation map in the same coordinate system as the control network at each site.

Task III.4c-6: Integration of Photogrammetry and Hydro-acoustic Data

The integration of photogrammetry and hydro-acoustic data task integrates the three dimensional terrain data derived from the softcopy photogrammetry and the three dimensional terrain data derived from the hydro-acoustic data. This task generates a single spatially explicit terrain model for each intensive study site. This terrain model is then used for the development of a base map in GIS for overlay of the digital aerial photographs, all biological observation data, and substrate/cover mapping at each site. In addition, the topographies are used as input for the generation of a computational mesh for use in the hydraulic and habitat modeling as described below.

Task III.4c-7: Computational Mesh Generation

The computational mesh generation task utilizes the integrated three dimensional terrain data derived in the previous step to generate a computational mesh suitable for use in 2-dimensional and 3-dimensional hydraulic modeling at a site. This effort requires an iterative process between hydraulic model calibration and revision in the mesh properties. Specifically, subdividing the computational mesh into smaller elements over some spatial locations can improve the calibration and/or simulation properties.

Task III.4c-8: Hydraulic Field Data Reduction

The hydraulic field data reduction task involves processing and summarizing the collected field data (e.g., water surface elevations, updating topography, substrate, cover, and vegetation). Water surface elevations need to be QA/QC'd and summarized in plots and spreadsheets. Substrate and vegetation coverage (where applicable) will need to be digitized onto the orthophotographs and stored in a GIS coverage. Locations where topography or velocities were collected by hand to fill in for missing data (where the boat access or GPS coverage were limited) should be QA/QC'd and combined with the photogrammetric and sonar generated digital terrain models. Where topographies are updated in these steps, the revised topography needs to be used for the generation of ~~a~~ new computational meshes.

Task III.5a: One-Dimensional Hydraulic Modeling

The techniques used to simulate hydraulic conditions in a stream can have a significant impact on habitat versus stream flow relationships determined in the habitat modeling (e.g., PHABSIM). The correct choice of hydraulic models as well as proper calibration often represents the most difficult step in the process of analyzing instream flows. The hydraulic simulation programs in PHABSIM assume that the shape of the channel does not substantially change with stream flow over the range of flows being simulated. In practice, small variations in the bed topography will often occur between field data collection efforts at the high and low flows. If these differences are small, then they are effectively ignored in the analyses. However, if significant changes in bed topography do occur between data collection field trips, these data should be treated as independent estimates of the hydraulic properties within the channel and used as independent data sets in the hydraulic model calibrations and simulations. These independent data sets should be collected if possible during the descending limb of the hydrograph to minimize affects associated with changes in channel geometry.

Simulated hydraulic characteristics are the water surface elevations (i.e., depth) and velocities, in that order. Water depths are calculated in the habitat programs from water surface elevations simulated in the hydraulic programs. The water surface elevations are assumed to be the same across a single cross section (although depth varies since it is calculated by subtracting the bed elevation from the water surface level). In contrast, velocity varies from cell to cell across any cross section.

The approaches available for calculation of water surface elevations are: (1) stage-discharge relationships, (2) Manning's equation, and (3) the step backwater method. The absolute minimum data set used in the application of PHABSIM requires at least one set of water surface elevations. In standard practice, at least three sets of water surface elevations are targeted for collection along with at least one and preferably additional sets of velocity measurements where ranges of simulated discharge are desired in complex channel geometries. As noted previously, collection of velocity data sets should be targeted for the descending limb of the hydrograph.

Task III.5a-1: Hydraulic Model Calibration

The first step in hydraulic modeling within PHABSIM is the calibration and simulation of water surface elevations. The recommended field data collection strategy discussed above allows for all of the following programs and approaches to be used:

IFG4 The IFG4 model uses a stage-discharge relationship to calculate water surface elevations at each cross section. Each cross section is treated independent of all others in the data set. The basic computational procedure is conducted by performing a log-log regression between observed stage and discharge pairs at each cross section. The resulting regression equation that describes the stage-discharge relationship is then used to simulate water surface elevations at all flows of interest.

MANSQ The MANSQ program utilizes Manning's equation to calculate water surface elevations on a cross-section by cross-section basis and therefore treats each cross section independently. Model calibration is accomplished by a trial and error procedure to select a ß coefficient that minimizes the error between observed and simulated water surface elevations at measured discharges.

WSP The Water Surface Profile (WSP) program uses a standard step backwater method to determine water surface elevations on a cross section by cross section basis. The WSP program requires that all cross sections being analyzed in a given model run be related to each other in terms of survey controls. That is, each cross section hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common datum. The model is initially calibrated to a measured longitudinal profile of the water surface elevations by adjusting Manning's roughness at each cross section and then to subsequent measured longitudinal water surface profiles at other discharges by adjusting the roughness modifiers used within the model. This approach generally requires all hydraulic controls within the modeled reach to be represented by cross sections.

The particular choice of a single model or a particular model for specific ranges should be based on model performance (i.e., accuracy of model results in comparison to measured values).

The second step in hydraulic modeling within PHABSIM is the calibration and simulation of velocities. The IFG4 program is the principal tool used to simulate the velocity distributions within a cross section over the required range of discharges (i.e., the mean column velocity in each wetted cell in a study cross section at each simulation discharge). One approach used is to distribute velocities across a channel using empirical observations (i.e., measured velocities) to solve “n” in Manning's equation (in this context “n” acts as a roughness distribution function across the channel). The channel is divided into cells and the velocity calculated for each of these cells. The usual practice is to use one set of velocities for a particular range of discharges. The program can be used when no velocity measurements are available where the velocity will be distributed across the cross section as a function of flow depth. Where multiple velocity measurements are available, IFG4 can be used to simulate the velocities over specific ranges of discharge using specific velocity calibration sets or by regression. At present, Washington State resource agencies prefer the use of a regression approach based on multiple velocity data sets. The choice of a single velocity set for all ranges of simulated discharges or different velocity calibration sets for specific ranges of simulated discharges can only be determined from evaluating model simulation results.

In addition, the calibration procedure should focus on the simulated velocities at flows greater than the calibration flow to ensure unrealistic velocity magnitudes do not occur in edge cells. This phenomenon can occur as an artifact of the IFG4 simulation algorithm and is most often corrected by imposing limits on the Manning’s n values or specification of a Manning’s n value in specific computational cells. The ‘best’ approach is to attempt to collect velocity calibration sets that bracket the range of discharges to be evaluated.

Task III.5a-2: Hydraulic Model Validation and Flow Simulation

In the case of reliance on 1-dimensional hydraulic simulations of water surface elevations and velocities (i.e., PHABSIM), model validation should be approached from several perspectives. In terms of water surface elevations, the difference between observed and simulated water surface elevations at the calibration flows is the primary criteria (e.g., +/- 0.05 feet). The tolerance between observed and simulated values is somewhat dependent on the nature of the stream and the variance in the observed water surface elevations at a specific cross section. Further validation of the hydraulic simulation of water surface elevations is derived from an examination of the longitudinal profiles where water should not 'flow uphill'. A fourth (or more) set of observed water surface elevations are often collected at each cross section to compare against the simulated conditions when time and budgets permit.

Velocity validations are most often approached from comparison of the simulated velocity profiles at alternative discharges where a second or third set of velocity profiles have been collected at each cross section. In addition, the functional relationship of the Velocity Adjustment Factors (VAF) over the range of simulated discharges should follow a theoretical pattern although in some instances, a departure from this theoretical relationship is to be expected. Other diagnostics such as the Froude number should also be examined as part of this process.

Task III.5b: 2/3-Dimensional Hydraulic Modeling

Two and 3-dimensional flow models require various boundary conditions such as the beginning downstream water surface elevations, discharge, accurate 3-dimensional channel topography, and spatially distributed substrate or roughness. In addition, accurate results require calibration and validation data in the form of longitudinal water surface profiles and measured velocities. These data requirements have been outlined under various tasks above. The quality of these data is extremely important to ensure modeling is accurate. The actual models solve a simplified form of the 3-dimensional Reynolds-averaged Navier-Stokes equations. It is possible to solve the equations in their fully 3-dimensional form, however, in streams with a relatively high width-to-depth ratio in which plan form changes are dominate, it becomes both acceptable and computationally more efficient to depth average the equations (i.e., use a 2-dimensional model) (Rodi et al., 1981) and to parameterize what 3-dimensional effect would be expected. The effects of bottom friction are accounted for using the Darcy-Weisbach or Chezy friction factor. Detailed examples of the use of these types of hydraulic models can be found in Tarbet (1997), and Tarbet and Hardy (1996).

Task III.5b-1: Hydraulic Model Calibration

The hydraulic model calibration task involves a two-step process. The first step entails the initial development of the stage-discharge relationships at the upstream end of the reach and at each of the downstream control points at each intensive study site. These relationships are required for basic model calibration and simulation of target discharges. The next step requires the initial calibration of water surface elevations in the model to the observed water surface elevation at the initial calibration discharge. This is accomplished by adjusting roughness or other model parameters such as eddy viscosity until measured and modeled water surface elevations at each of the calibration flows coincide.

Task III.5b-2: Hydraulic Model Validation and Flow Simulation

Once the hydraulic model is calibrated, the measured velocity distributions collected with the acoustic doppler profiler and/or velocity meter are compared to the modeled velocity distributions at each calibration discharge. This step is used to assess the quality of the hydraulic modeling. Summary statistics of these comparisons should be generated to aid interpretation of the reliability of the hydraulic modeling and potential impacts on use of the simulation data during other modeling (e.g., habitat, sediment). This step provides an important QA/QC check on the modeling process. Large differences between the modeled and measured velocity patterns frequently are the result of inadvertent topography (i.e., mesh quality), field measurements, or hydraulic modeling errors. Any such problems should be identified and corrected. Following the hydraulic modeling validation, the entire range of flows should be modeled to provide input for other modeling needs. Typically, 15 to 25 different discharges are modeled at relatively even flow increments over the range of flows desired for analysis at each site.

Task III.6: Hyporheic Zone Determinations

The importance of the hyporheic zone (i.e., areas of ground water infiltration within the channel) in rivers to spawning salmonids in terms of redd locations or for use as thermal refugia is well documented in the current fisheries literature (e.g., Dauble and Geist, In press; Geist and Dauble, 1998). The potential assessment of the flow dependent nature of hyporheic zones within each study reach should be determined through the use of the methodology proposed by Geist and Dauble (1998) and Geist et al. (1998). Piezometers should be installed in at least three locations along the longitudinal extent of each study reach and measurements collected over a range of discharges associated with the seasonal flow patterns. Analysis of these data should follow the guidelines outlined by these authors and integrated into the overall assessment framework as described below.

Task III.7: Channel Maintenance Flows (Sediment)

The high flow component of the instream flow regime needs to be evaluated in light of the sediment processes that affect channel plan form and size, cross section geometry attributes, and the surface sediment characteristics of the channel and associated floodplain. Bankfull and channel thalweg elevation slope and quantitative sediment characterization (i.e., pebble counts) should be collected to permit the evaluation of critical shear stress, over bank flooding frequency, and other parameters necessary to evaluate the efficacy of the proposed high flow regime. Existing efforts are underway within WRIA 1 by the USGS to quantify the hydrologic processes in a spatially and temporally distributed manner. The USGS effort will quantify the flow characteristics required at specific locations of interest. Key hydrologic parameters include the estimation of the return period associated with bank full discharges and monthly flow duration curves.

More intensive complete bed load and suspended load sampling and subsequent modeling are considered beyond the scope of this initial effort. However, such sampling may be considered for specific reaches as part of more focused efforts to address specific management needs.

Task III.8: Riparian Maintenance Flows

The high flow component of the instream flow regime needs to be evaluated in light of the interaction between sediment and hydrologic processes that ultimately affect the riparian communities along river corridors. This evaluation can be integrated with Task III.7 by extending the survey data of the channel cross sections to an elevation associated with the beginning with the upland vegetation. This information can then be utilized in conjunction with the hydraulic modeling of water surface elevations and expected flow exceedance values to assess the magnitude of discharges necessary to inundate the riparian vegetation. Although the specific quantitative process by which riparian flow regimes can be quantified is an emerging science, an evaluation of several techniques should be assessed as part of the evaluations and a determination of the most appropriate method(s) considered in light of data and modeling results for specific locations within the watershed.

IV. Chemical Processes

Two of the more important elements of chemical processes that affect stream dwelling organisms are temperature and dissolved oxygen. However, other factors of concern that have already been identified within WRIA 1, such as elevated nitrates and fecal coliform, are associated spatially with agricultural and municipal point and non-point pollutant loadings. The following tasks are oriented toward a preliminary program of water quality and temperature modeling that relies on existing data sources to a large degree but provides a framework for more site-specific data collection in those instances where constituents of concern have been identified.

The primary purpose of this effort is to develop the capability to accurately simulate the longitudinal profiles of temperature and dissolved oxygen (and other parameters) within a study area as a function of season, flow rate, and different meteorological conditions. Other parameters considered to be important (e.g., nitrates, pH, turbidity, suspended sediment, etc.), should also be included in this analysis where deemed important for a particular stratum.

Task IV.1: Water Quality and Temperature Data Collation

The water quality and temperature data collection task is oriented toward the evaluation of existing data records at all available locations over time in which temperature, meteorological data, and other water quality constituents have been measured. This should be approached such that the spatial locations, times, and constituents are collated in a manner that permits access to this information specifically to aid in the identification of available calibration data and initial conditions for water quality and temperature modeling efforts at each study site. The review of these data should also serve as the basis for identification of key system locations where focused water quality sampling may be needed to address critical data deficiencies. As noted previously, at each of the selected intensive study sites, continuous temperature and dissolved oxygen probes should be established to aid in this regard.

Task IV.2: Water Quality and Temperature Model Selection

Based on the strategic needs for this project in conjunction with other efforts (e.g., salmon restoration) available water quality and temperature models should be reviewed in light of data requirements, data availability, and modeling capabilities. This review should include not only fisheries resource managers but also other parties that may potentially rely on these models for other management programs. Selection of a target model(s) should also consider such factors as analytical time step (hourly, daily, monthly), computational capabilities (i.e., one or many conservative or non-conservative constituents), modeling components (i.e., nutrient dynamics, sediment oxygen demand component, etc.) and ability to handle anticipated spatial requirements (i.e., point loads, non-point loads, etc.).

Task IV.3: Water Quality and Temperature Model Calibration

Once a model(s) has been identified for application, the model should be calibrated against the available data for all target constituents and temperature. In the event that more than one simulation model is required (e.g., coupled water quality and temperature capable of generating only mean daily temperatures versus a separate temperature model capable of simulating maximum and minimum daily temperatures) then each model should undergo independent model calibration. Target calibration criteria will in large part depend on the amount of available data and nature of the resolution of simulated target constituents. At a minimum, it is anticipated that mean daily temperature and associated dissolved oxygen simulations will be required for the instream flow assessments, although diel simulations of both temperature and dissolved oxygen may be required at selected study sites.

Task IV.4: Water Quality and Temperature Model Validation

Each model should be validated against an independent set of data and the uncertainty in the model predictions quantified for all constituents. This step may require a time lag in order to acquire sufficient data for initial model calibration versus the collection or availability of independent data sets for model validation.

Task V. Biological Processes

Two goals of the biological analysis are to generate an understanding of the biological processes for each study stream (or segment) and to support the iterative process of validation and improvement of all biological modeling.

Task V.1: Characterization of the Invertebrate Community

The characterization of the invertebrate community task should entail the collection of three replicate drift samples below a riffle for each selected stream reach. Three replicate drift samples should be taken from three separate locations corresponding to the left, center, and right sides of the stream channel if possible.

This sampling effort should be conducted on a monthly basis (or quarterly depending on budget and staff constraints) to determine the expected seasonal changes in drift availability and characteristics. In addition, major substrate types within each study reach should be sampled with three replicates on a quarterly basis to determine the benthic community composition and density. Drift and benthic sampling should follow established protocols (e.g., Shoemaker et al., 1997).

Task V.2: Invertebrate Sample Processing

Aside from the importance of characterizing the invertebrate community of the aquatic resources at each site, one of the proposed modeling approaches involves the application of an individually mechanistic based bioenergetic model for salmonids. In order to apply this model, the hydraulic model output must be integrated with both temperature and food availability. The food availability is determined from an estimate of the drift density and size characteristics. The drift and benthic samples collected at each sampling site need to be processed in order to derive these density and size characteristics. Initially, identification of the number by Order or Family (depending on the taxa) should be sufficient for instream flow assessment modeling. Size characteristics of each taxa should be estimated to the nearest millimeter when processing the samples. Processing of the invertebrate samples should follow published laboratory guidelines. All processed samples should be preserved and retained for use in potential future taxonomic or related work.

Additional analyses of the invertebrate samples in conjunction with other physical, chemical, and biological data to obtain watershed level assessments should also be considered (e.g., Shoemaker et al., 1997). These types of analyses can help development of reference states in terms of physical, chemical, and biological components suitable to assess relative ecosystem health.

Task V.3: Fish Species and Life Stage Habitat Utilization

The fish species and life stage habitat utilization task should focus on the verification of fish species and life stage use within each study reach in a manner that maximizes the potential for validation of both physical habitat and bioenergetic (or other) modeling. Each habitat type available within a study reach should be sampled using equipment types and sampling strategies appropriate for each target species and life stages. To some degree, equipment types and sampling strategies may be dictated by the physical characteristics of the stream as well as behavioral traits of the target species and life stages. In those instances where water clarity and physical conditions permit, direct observations using snorkeling or scuba are preferred. However, pre-positioned electro-fishing nets, hand seines, gill nets, trammel nets, hoop nets, etc., should also be considered. Experience of local fisheries resource managers should be relied upon in the selection of equipment type(s) and sampling strategies.

For each location in which a sample is collected, the coordinates of the sample in terms of the established reference control network should be noted. The type, number, size, and sex should be noted for all collected species. The discharge on the date(s) of collection should also be determined and indexed to the downstream hydraulic control for each study site. For each collection, the depth, velocity, substrate, cover, continuous temperature and dissolved oxygen, and other pertinent water quality parameters should be measured and recorded. These data can subsequently be used in the validation of Habitat Suitability Criteria (HSC) or for the development of HSC.

Task V.4: Fish Habitat Utilization Data Reduction

The data collected under the previous task should be entered into electronic format following standard QA/QC procedures such that they can be integrated within the GIS coverage for each intensive study site. The GIS will be used to associate spatial location, species, life stage, size, and all related physical and chemical data. These related data include velocity, depth, distance to cover for each collection set. The integration of these data will serve as a basis for the validation of all biological or habitat modeling efforts.

Task V.5: Selection of Interim HSC

Due to the prohibitive time and cost constraints associated with attempting to develop site specific HSC for each stream reach across all potential strata, interim HSC need to be selected. Available HSC for all target species and life stages should be assembled from the literature for consideration for use within WRIA 1. Once these potential HSC have been assembled, a formal HSC workshop (or process) involving knowledgeable fisheries experts and resource managers should be convened to review, evaluate, and select interim HSC for application within WRIA 1. This should consider the potential selection of HSC specific to stream size and characteristics associated with the range of strata anticipated to reflect system variability throughout the basin.

Task V.6: Validation of Interim HSC

The validation of the interim HSC will be contingent on the available biological field data for specific species, life stages, and season. Validation should be approached from two basic directions. The first approach should involve a comparison of the available biological data for specific species and life stages with the selected interim HSC criteria by plotting the normalized frequency distributions for depth, velocity, substrate, and other variables such as temperature against the respective HSC. This approach should also involve formal HSC testing with one or more 'transferability' tests suggested in the literature depending on data availability for specific species and life stages. At a minimum, the test proposed by Thomas and Bovee (1993) and the test by Groshens and Orth (1993) should be considered.

It should be noted however, that documented problems with these tests may preclude their application in a definitive manner and alternative testing approaches may be warranted such as computation of Manly's alpha preference index. The second validation approach should involve validation of the species and life stage specific HSC at each intensive study site based on the field derived presence and absence data using all habitat or bioenergetic based modeling as described below. In all instances, adjustments or selection of new HSC based on these comparisons will be considered and reviewed by the fisheries experts and resource managers involved throughout the study.

Task V.7: Physical Habitat Modeling

The physical habitat modeling will be approached differently depending on the specific life stages considered for different species. For example, spawning analyses should only include habitat units that species are known to utilize for spawning, include depth, velocity, and substrate and rely on the integration of the hyporheic analyses described previously. Analysis of fry and juvenile habitats should incorporate restrictions in the simulations that evaluate distance from the shoreline or presence of cover to reflect the known behavioral dependences to these factors in salmonids. Other factors to be included or excluded should be addressed during the HSC selection process by reliance on the species experts. The analysis of physical habitat should generate the spatial distribution and quality of habitat within each study site as a function of the range of simulated discharges. The physical habitat simulations will then be integrated with temperature and water quality modeling results within the assessment framework to evaluate the instream flow needs.

Task V.8: Physical Habitat Modeling Validation

Spatially explicit maps of simulated fish habitat quantity and quality for each species and life stage based on HSC criteria should be generated at each site for all modeled flows. In addition, these spatially explicit maps should include individual and combined suitability factors to aid in the validation of the HSC. These maps should be incorporated into a GIS framework and combined with the spatially explicit biological data collections. Histogram summaries of the habitat utilized by fish compared to the modeled habitat suitability should be generated where biological data for specific species and life stage are available. This will provide a QA/QC check on the veracity of the habitat modeling. In any instance where this step shows that the modeling results for a specific species and life stage does not match observed distributions within the study reach, a review of the likely causative factors should be undertaken and remedial actions taken (e.g., revised HSC).

Task V.9: Bioenergetic Modeling

The bioenergetic modeling task should utilize a mechanistic based modeling approach to predicting Net Energy Intake (NEI) for drift feeding stream salmonids using habitat and physiological variables as inputs. The method uses a foraging model to determine NEI by subtracting energy costs and losses from the gross energy intake obtained by simulated prey capture at focal point locations within a stream. The foraging model utilizes the predation model of Holling (1959) in conjunction with components of the prey capture model of Hughes and Dill (1990) to determine the rate of prey capture as a function of fish size, localized water velocity profiles and water depth, drift density, water temperature, and time budgets. Physiological based input parameters for the model have been estimated from the literature. The model is built on small spatial scale (microhabitat) calculations of NEI that can be aggregated to provide measures of NEI at the mesoscale (habitat unit: run, pool, riffle, etc.) or macroscale (reach, river, etc.) habitat levels. These small scale and resulting aggregated measures of NEI are directly related to growth, abundance, and biomass potential of streams and thereby provide an alternative method of assessing flow dependent stream habitat quantity and quality compared to physical habitat based modeling. For this type of modeling to be effective, 2-dimensional or 3-dimensional hydraulic simulations are critical.

Task V.10: Bioenergetic Modeling Validation

Spatially explicit maps of simulated fish habitat NEI for each species and life stage should be generated at each site for all modeled flows. These maps should be incorporated into a GIS framework and combined with the spatially explicit biological data collections. Histogram summaries of the habitat utilized by fish compared to the modeled NEI should be generated where biological data for specific species and life stage are available. This should provide a QA/QC check on the veracity of the modeling. In any instance where this step shows that the modeling results for a specific species and life stage does not match observed distributions within the study reach, a review of the likely causative factors should be undertaken and remedial actions taken (e.g., revised energetic relationships).

VI. Integrated Assessment Framework

The empirical based assessment of flow regimes relies implicitly on the correct interpretation of the measured and modeled components in light of the understanding between physical, chemical, and biological processes as a function of flow regimes.

Biological data is inherently noisy and failure to delineate and understand the underlying processes, which affect these responses, will preclude the defensible validation of the instream flow needs. It is strongly recommended that a clear delineation of how each component will be evaluated and assessed in light of the known or expected needs and responses of the respective life history requirements of each species and life stage be contemplated at the outset of the study. Implementation of specific study elements should only be undertaken with a clear understanding of how application of methodologies and the specific results will be integrated within the overall assessment and evaluation process. The following brief discussion on various approaches is provided to illustrate the range of potential evaluation criteria that may be considered in the process.

In many instream flow studies, a number of species and life stages are considered to be important for evaluation of instream flow needs. For example, a stream may contain several species of salmon, resident salmonids, and important non-game species (e.g., tribal trust species). The analyses undertaken may likely result in a family of habitat versus discharge functions as illustrated in Figure 4. For some time periods of the year many if not most of these species and life stages may be present in the system. Therefore, the investigator is faced with a difficult task of integrating all these curves in a coherent manner to establish an ecologically acceptable flow regime.

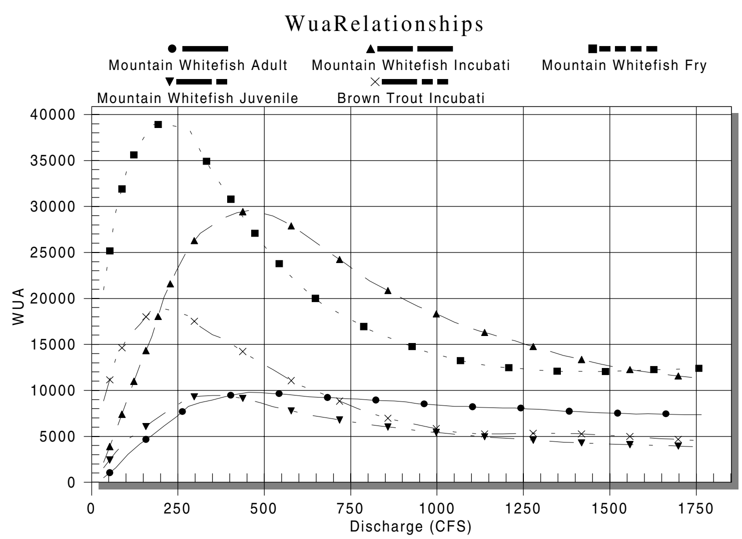


Figure 4. Example WUA (square feet per 1000 feet of stream) versus discharge relationship for a several species and life stages.

Use of a Most Sensitive Species and Life Stage

One approach to integrating multiple habitat relationships is to select the single species and life stage that is most sensitive to changes in flow during a critical period upon which to base the instream flow assessments. Alternatively, a particular species and life stage may be considered the most important from a management perspective such as spawning chinook salmon in a system where the management goal is recovery of these populations. Flows could be selected on this single species and life stage within a specific time period while attempting to minimize potential adverse conditions to other species and life stages. In some situations, a reduction in the habitat quantity or quality of a primary target species and life stage can be made such that other species and life stages still retain what are considered adequate levels of habitat availability. However, some applications are not readily amenable to the use of the most sensitive species or critical species and life stage (i.e., they all are the focus of management objectives). In this instance a post analysis guilding approach is sometimes possible.

Post Analysis Guilding

A post analysis guilding approach can take on several forms depending on the context of the project and management objectives. One approach that has been used involves the construction of a community level habitat versus flow curve. A community habitat curve can be constructed utilizing the original habitat versus discharge relationships or by using a set of normalized habitat versus discharge functions.

Species/Life Stages Normalized by Maximum Habitat.

If normalized habitat functions are to be used, then the first step is to re-scale each individual species and life stage habitat versus discharge curve to the maximum value of habitat for each species and life stage (i.e., each curve is re-scaled as a percent of the maximum or optimal habitat) as illustrated in Figure 5.

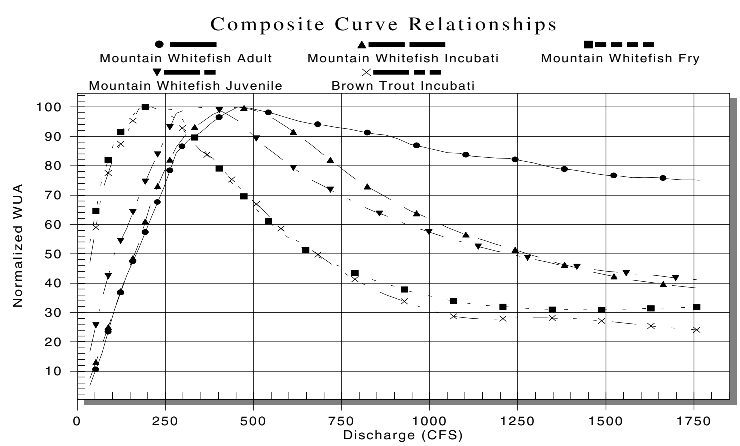


Figure 5. Example or normalized WUA (Percent of Optimal Habitat) versus discharge relationship for target species and life Stages. Each WUA curve is normalized by its maximum habitat value.

The investigator can then combine these curves (or the original un-scaled curves) using a weighted arithmetic average to produce a single curve as illustrated in Figure 6. The relative weighting factors for a specific critical period for each species and life stage can be selected to represent the management objectives for the system and should be defined at the onset of the project if possible. The investigator may develop a community curve for specific periods of the year based on the unique combinations of species and life stages identified by a species periodicity table for the site. It is also possible that the relative weighting factors used to construct the community curves may change between time periods to reflect the relative importance or sensitivity of specific species and life stages during a particular time period. For example, an endangered species may receive a weight of 2.0, while all other species and life stages may receive a weight of 1.0, or spawning may be weighted more than fry during the spawning period. The community curves can be used in subsequent evaluations such as time series and habitat duration analyses. It is strongly advised that individual species and life stage habitat relationships be checked to ensure potential instream flows provide consistency in the results.

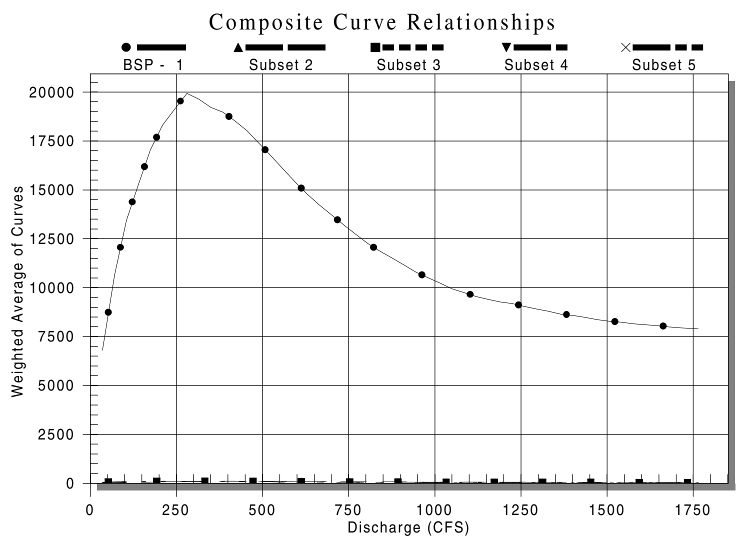


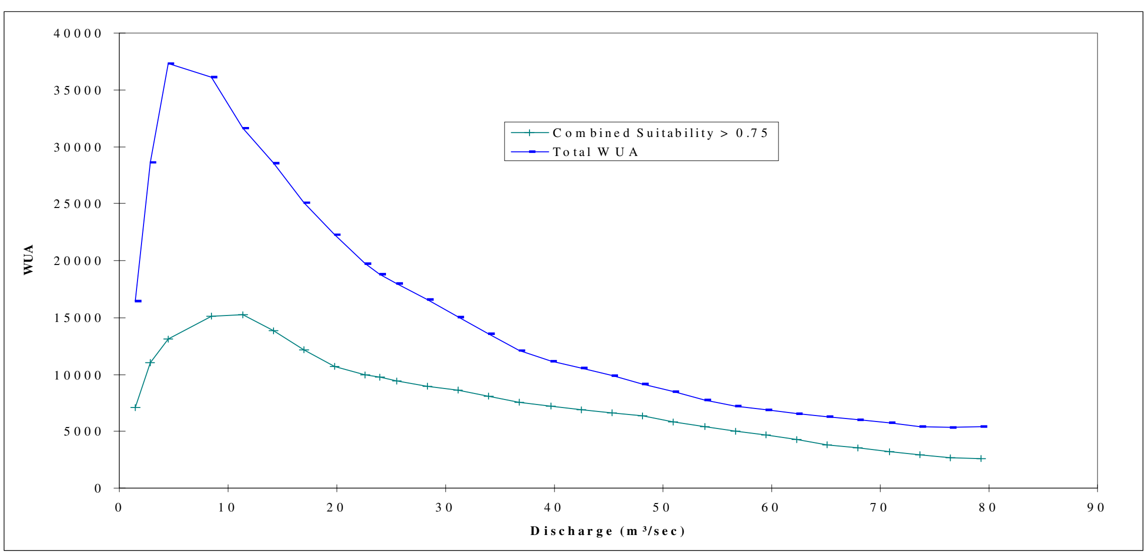
Figure 6. Example of a community level percent of optimal habitat versus discharge curve.

Alternatively, an investigator may simplify the results shown in Figure 4, for example, to eliminate ‘redundant’ habitat versus discharge relationships. In this approach, curves that have the same basic magnitude and functional relationship can either be eliminated or averaged together to generate a single curve which in essence represents the guild of species and life stages with similar fundamental relationships between habitat and flow (see Mountain Whitefish Fry and Brown Trout Incubation in Figure 5). In some instances, this combining or guilding is also conducted utilizing normalized habitat functions since most applications are focused on relative changes in habitat and not necessarily on the actual magnitude of the habitat change. Similarity in the functional relationships between habitat and discharge for different species and life stages in fact is not uncommon and in a sense is to be expected. For example, fry and juvenile curves for many salmonids actually exhibit very similar habitat requirements that follow known obligate habitat use for these early life stages. It is also not uncommon for different life stages for different species to utilize similar habitats that in turn are reflected in similar suitability curves and hence similar habitat versus discharge relationships. The final set of guilded habitat functions can then be used to construct a community level curve as described above, or the most sensitive species within a critical period may be selected for consideration in further analyses. As mentioned previously, in all cases, the individual species and life stage habitat curves are again checked for implications of a selected flow regime once these results have been used to assist the investigator in the instream flow selection.

Consideration of Quantity Versus Quality

As illustrated in Figure 4, the basic habitat versus discharge relationship represents an aggregation of the component cell Weighted Usable Area (WUA) values across all cells at a specific discharge for a given species and life stage. Therefore, the results presented in Figure 4 cannot be directly used to ascertain the difference between the total magnitudes of habitat that is represented by all cells having a low suitability versus a few cells that contain high suitability. Computational techniques are available that permit the user to determine the component areas associated with given thresholds of combined suitability. This is illustrated in Figure 7 for a combined suitability greater than 0.75 for adult brown trout.

Figure 7. Example of the differences between Total WUA and WUA associated with



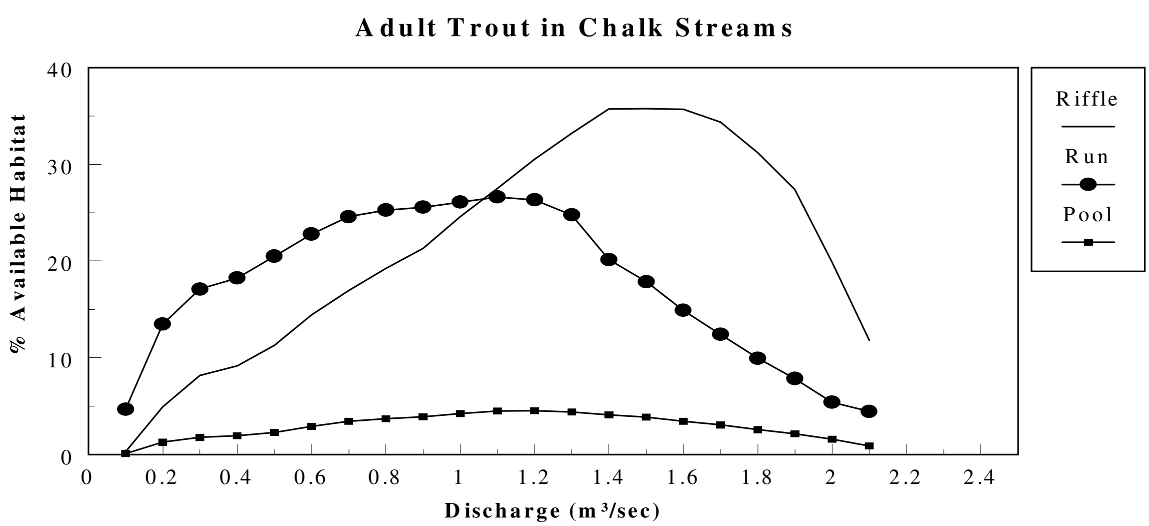
high quality habitat (i.e. Combined Suitabilties ≥ 0.75).

As can be seen, the peak of the total habitat curve does not always correspond with the peak of highly suitable habitat conditions. The investigator should carefully consider the biological implications of selecting flows that maximize total habitat versus the consideration of an alternative flow that may maximize the area associated with high quality habitat. It should be remembered that all the techniques described above could be used with high quality habitat versus flow functions in a manner equivalent to using the total habitat curves.

Evaluation of Mesohabitat Specific Conditions

Since the modeling approaches describe above can be used to generate output on a habitat specific basis, the investigator can develop habitat versus flow functions for specific species and life stages by mesohabitats as illustrated in Figure 8. This type of analysis can focus the investigator on species and life stage specific sensitivities to particular habitat types that may be important during critical periods of the year. For example, an analysis may focus on riffle type habitats during the spawning season in lieu of other less sensitive life stages and mesohabitats using this approach. This type of analysis can also facilitate the aggregation of mesohabitat versus flow functions into composite habitat versus flow functions when the proportion of habitat types may change as a function of discharge, or where a gross evaluation of habitat improvement works is desired.

Figure 8. Example of mesohabitat specific habitat versus flow functions.



Evaluation of Suitability Curves

In many studies an investigator may have selected a cross section at a specific location in the stream where a known spawning redd was observed. In this instance, the investigator can examine the spatial distribution of combined suitability across the cross section to determine if the suitability curves correctly demonstrate suitable habitat conditions at the location of the spawning redd as illustrated in Figure 9. A prediction of low combined suitability at the known redd location should cause some concern and a more detailed evaluation of the hydraulic simulations (primarily velocity or channel index) in conjunction with a re-assessment of the suitability curves should occur.

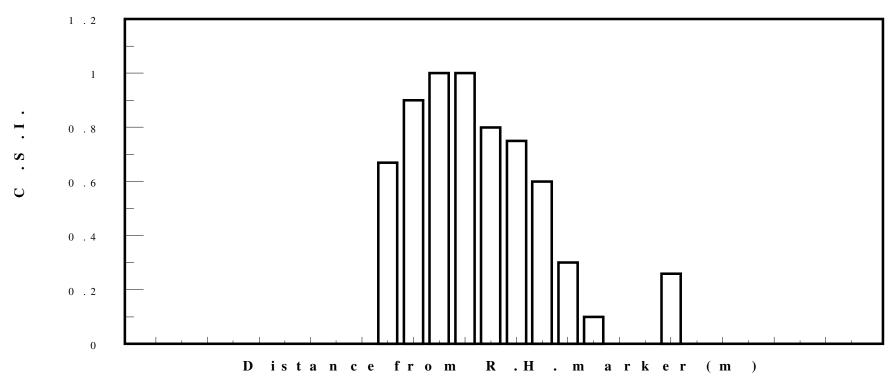


Figure 9. Spawning Trout habitat distribution within a study cross section at a selected flow (C.S.I. equals the combined suitability of depth, velocity, and substrate).

Decomposition of Single Parameter Suitability

An investigator may find that the evaluation of which specific suitability factor is contributing to the estimate of the total or the quality of habitat is important. This can be accomplished, for example, by modification of the suitability curves so that only a single parameter such as velocity is retained, while both depth and channel index are set to a 1.0 for all values. This type of analysis can reveal whether depth, velocity, or channel index (i.e., substrate and/or cover) is the controlling factor over specific ranges of discharges as illustrated in Figure 10. In addition, when combined with an analysis of mesohabitat specific evaluations, this type of assessment can lend insight to the physical basis for habitat specific sensitivity to flow for a critical life stage.

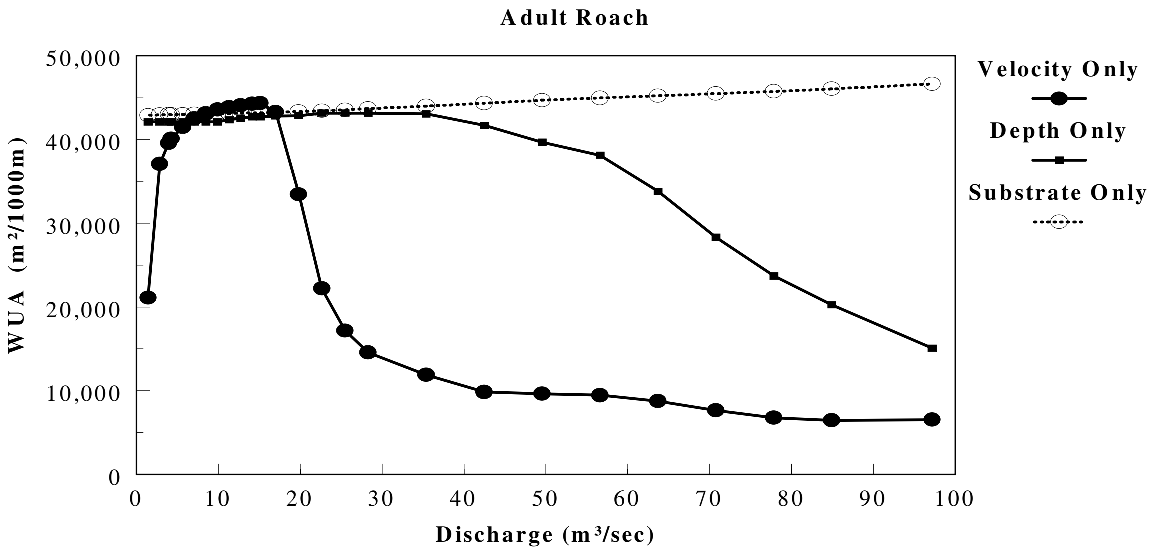


Figure 10. Example of single parameter habitat versus discharge relationships.

Spatial Niche Analysis

The hydraulic simulations can also be used to examine the spatial niche of a stream as a function of discharge in terms of depth, velocity, or in some circumstances channel index. An investigator may find that suitability index curves are not readily available, or may simply wish to examine the flow dependent characteristics of spatial niches as part of the overall study. In this type of approach, a fish community may be partitioned by species and life stages into a simple spatial matrix representing habitat use along a gradient of depth and velocity as illustrated in Table 2. Note that in this type of analysis, no species or life stage HSC are necessary since only a community level habitat (i.e., spatial niche) partitioning is used. Suitability curves that define usable habitat as 1.0 over each combination of depth and velocity can be used to compute the area associated with each spatial niche at each discharge. These relationships can then be aggregated to construct a cumulative area versus discharge relationship as illustrated in Figure 11. In Figure 11, each line represents the component area that each spatial niche in Table 2 contributes to the total surface area of the stream at a specific discharge.

Table 2. Example of a Hypothetical Spatial Niche Indicating Component Habitat Partitioning by Resident Species/Life Stages.

		Depth Gradient (m)		
		0 - 0.5	0.5 - 1.0	≥ 1.0
Velocity Gradient (m/s)	0 - 0.5	Brown Trout Fry Salmon Fry Grayling Fry Dace Fry	Brown Trout Juvenile Salmon Juvenile Dace Juvenile Dace Adult	Dace Adult Winter Brown Trout Adult Winter Salmon Juvenile
	0.5 - 1.0	Dace Juvenile Dace Adult	Grayling Juvenile Brown Trout Adult Salmon Juvenile	Grayling Adult Brown Trout Adult Salmon Adult
	≥ 1.0	Dace Adult	Salmon Spawning	Brown Trout Adult Salmon Spawning

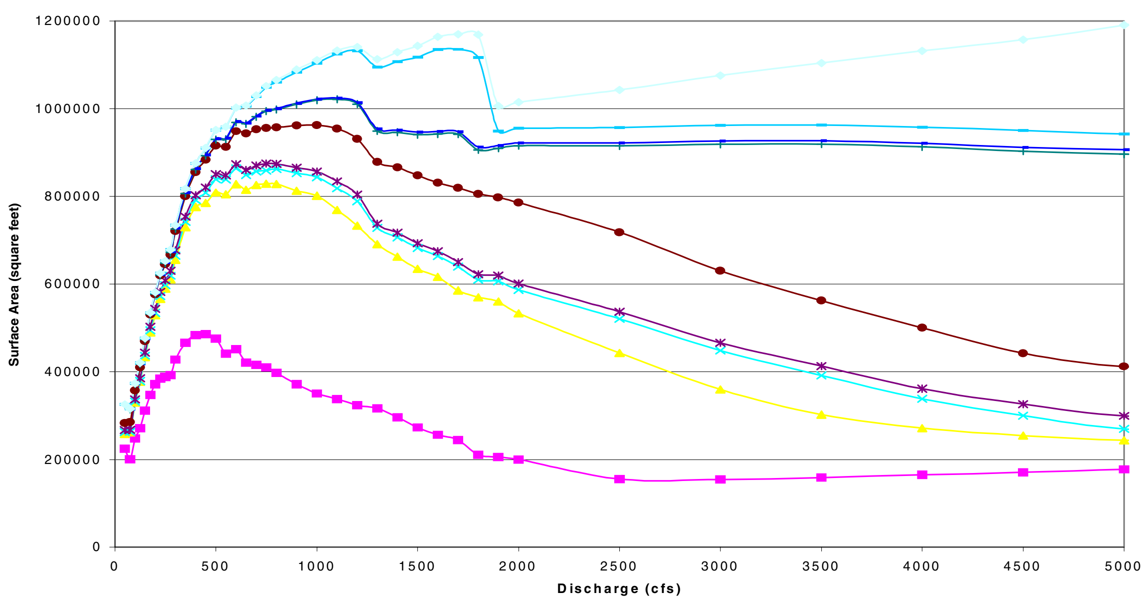


Figure 11. Example of Spatial Niche Composition versus Discharge.

It is also possible to use these results to compute a variety of ecological based indices such as a diversity index. The diversity index can be computed utilizing the available habitat areas at each flow to produce habitat diversity versus discharge relationships. These relationships can then be examined in light of specific discharges and the associated amounts of specific areas represented by specific habitat niches or overall habitat diversity. This examination may lead an investigator to select a discharge or discharge range that either maximizes the spatial niche of a particular community element(s) or favor a broader range of diversity of available habitats. These analyses and their interpretation should be evaluated in light of known or expected unimpaired historical conditions using reference sites if possible.

Habitat Time Series

All other factors being equal, it is a reasonable assumption that current populations of fish are dependent to some degree on the antecedent history of habitat availability. It is also logical to assume that future population levels will be influenced by the time dependent characteristics of habitat availability. In many instances, it is the time dependent characteristics of the habitat time series that ultimately may limit a particular life stage and therefore control the fish population. This has often been referred to as a limiting life stage or population bottleneck. An instream flow assessment can explore these potential limiting conditions for specific species and life stages through the application of habitat time series. This extension of the basic model results of available habitat versus discharge to temporal predictions of habitat can provide important information for the examination of habitat availability that may influence long-term changes in fish and invertebrate populations. It must be noted however, that habitat time series entail additional assumptions about biology. Most of these assumptions have not been tested and therefore these results should only be utilized in conjunction with all other available information when assessing instream flows.

In order to conduct a habitat time series analysis, one needs to have derived the basic habitat versus flow relationships for target species and life stages and also obtained the associated time series of flow(s) at the study site. The major premise of habitat time series analysis is that habitat is a function of stream flow and that stream flow varies over time. The basic computation steps of a habitat time series are illustrated in Figure 12, where the habitat versus flow function (i.e., WUA vs. Discharge) is integrated with the flow at each time step to derive habitat availability at each time step. The habitat time series can then be analyzed to derive a habitat duration curve similar to flow duration curves derived in hydrologic analyses as illustrated in Figure 12 and discussed below.

In its various guises, time series analysis provides a very valuable method of assessing the implications of different flow regimes. The most common approach generates habitat time series data for a study site both under natural conditions and alternative flow regimes as illustrated in Figure 12.

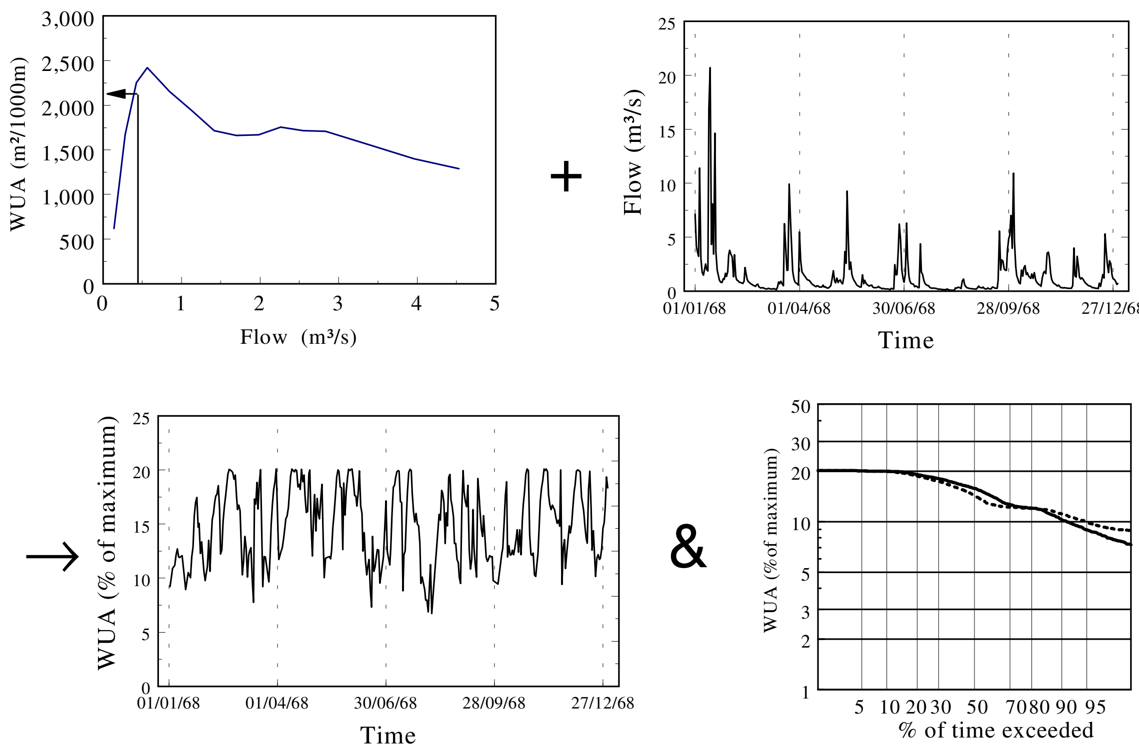


Figure 12. Development of a habitat time series and habitat duration curves.

Analysis of these outputs can take a variety of forms; the following are some of the more common approaches:

1: A simple comparison of the two (or more) sets of habitat time series data can identify periods where different flow regimes have greater or lesser impacts.

2: Using the above data, the percentage reduction in habitat can be calculated, again to assist in the identification of periods of greater or lesser impacts.

3: Mean monthly (or other time interval) habitat levels and mean monthly percentage habitat losses can be calculated to examine more general patterns of habitat change.

4: A combination of these analyses can be used to identify alternative flow regimes that minimize potential adverse impacts or provide habitat improvements for critical time periods or life stages to meet management objectives.

Once the habitat time series data sets have been calculated, the user may wish to aggregate values at some appropriate time interval such as using daily time steps aggregated to monthly, seasonal, or even yearly intervals, in order to examine habitat changes on a differential time interval basis. It is important to remember that some life stages such as incubating eggs require careful analyses when conducting time series given the length of time this life stage remains immobile within the stream bed. Special attention must also be given to flows associated with scour and deposition of fine sediments in the evaluations.

Commonly used summary statistics of habitat time series for any interval of time include:

Mean habitat   Median habitat   Minimum habitat   Maximum habitat

Index-A: mean of all the habitats between 50% and 90% exceedance, i.e. the majority of the low flow event

Index-B: mean of all habitats between 10% and 90% exceedance

Specific exceedance statistics e.g. 90, 95-percentile habitat values

Number of days below a habitat quantity threshold, or total threshold deficit

Habitat Duration Curves

Further analysis of habitat time series may be achieved using a variety of techniques developed for river flow analysis. The first example of this is the habitat duration curve (Figure 12). A duration curve, whether for flow, habitat, or another instream variable, displays the relationship between the variable and the percentage of time it is exceeded. These methods are of particular interest in the evaluation of how various flow regimes affect habitat available to individual life stages of a species.

Habitat Duration Threshold Analyses

The habitat duration threshold analysis technique (Capra et al., 1995) has been used to characterize periods of flow below a certain threshold habitat value. It allows the user to assess not only the number of low habitat events but also the length of time over which each low habitat event occurs. For example, habitat may drop below a threshold level for 10 separate days in a month, or it may drop below the same level for a single continuous period of 10 days within a month. These two scenarios would appear the same when plotted on a duration curve but may have very different implications for the target species/life stage in question. In this type of analysis, a habitat threshold level must be set by the investigator and the relative importance of both the number and length (i.e., number of time steps) over which habitat is at or below this threshold must be interpreted using the available knowledge of the target species/life stage in question.

Task VI.1: Hydrologic Based Assessments

Although a large amount of site specific data and modeling efforts will be undertaken as part of the recommended assessment framework, the evaluation of the flow regime should be undertaken in light of what are known to be important characteristics of flow regimes to aquatic resources. In this task, it is recommended that the hydrologic based analyses proposed by Richter et al. (1996) be used in conjunction with the other modeling efforts to help in the instream flow assessment process. This approach attempts to evaluate instream flow needs in terms of preserving the flow characteristics including inter- and intra-annual variability to protect important ecological processes within river corridors. Although this technique has not yet received wide application or rigorous validation in terms of species responses, it does examine the flow needs in light of the linkage between flow frequency, magnitude, duration, and timing that are recognized as important components of the aquatic ecosystem in rivers. These analyses should be used in conjunction with other modeling results to aid in the decision process for evaluating instream flow needs.

Task VI.2: Establishment of Hydrologic Scenarios for Evaluation

All of the physical, chemical, and biological data collection and modeling directed toward defining the instream flow needs will require the identification of specific flow scenarios to be evaluated. The planned effort by the USGS should allow the generation of flow statistics and time series at target study sites that represent different types of flow regimes (e.g., wet, normal, dry). The range and character of flow regimes to be evaluated needs to be determined on a site-by-site basis. In some instances, natural flow regimes associated with extremely wet, wet, normal, dry, and critically dry water year types may be sufficient for the evaluation of instream flow needs. At other locations, these water year types with and without existing or proposed diversions may need to be considered. The integration of the flow scenarios with other modeling components should consider physical habitat availability, energetic based evaluations, and water quality thresholds in terms of optimal, chronic, and acute exposure criteria.

Task VI.3: Habitat Time Series Analyses

The habitat time series analyses effort should entail the computation of habitat time series for target species and life stages at each study site utilizing each of the hydrologic scenarios identified in the previous task. For each of the analyses, the full complement of habitat time series metrics discussed above should be computed to help in the evaluation of flow regimes. The habitat time series should include not only physical habitat but also the NEI metrics derived from the bioenergetic based modeling.

Task VI.4: Water Quality and Temperature Evaluations

For each of the hydrologic flow regimes identified for analysis at each site, the corresponding water quality and temperature modeling needs to be computed. The results from these simulations should be used to examine differences between the flow scenarios in light of such factors as preferred or optimal temperature ranges for growth, or in terms of chronic and acute exposure rates. In most cases, the estimated unimpaired or natural conditions are used in time series to determine naturally occurring frequency, duration, magnitude, and timing of both chronic and acute levels as a baseline for evaluating the effects of alternative flow scenarios on these same criteria.

Task VI.5: Bioenergetic Based Evaluations

The hydraulic simulations, temperature simulations, and flow rates in conjunction with the food availability on a seasonal basis should also be used to evaluate each of the flow scenarios on expected incubation and growth rates for target salmonid species at each site. These analyses can help in the evaluation of how different seasonal flow regimes may affect anticipated growth rates, timing of out-migration for anadromous species, and related flow-temperature dependent relationships.

Task VI.6: Assessment of Instream Flow Regimes

At each of the study sites, the full complement of modeling results should be used to assess instream flow needs on a monthly or seasonal basis and include consideration of both channel and riparian maintenance flows where appropriate. In some instances, different instream flow requirements may be considered differently by water year type or even season where deemed appropriate. It is strongly recommended that a technical workshop be conducted to formulate a specific framework to objectively interpret these results in light of the specific legal and institutional constraints within WRIA1. This workshop should include independent instream flow experts as well as local, state, federal, and tribal aquatic resource managers. This should be initiated early in the process to avoid positional interpretation of results to meet special interest objectives late in the process.

Task VI.7: Development and Validation of an Instream Flow Extrapolation Procedure

The development and validation of an instream flow extrapolation procedure task should focus on the use of the modeling efforts at each of the intensive study sites specific to a particular strata to establish a mechanism by which a screening level instream flow recommendation can be determined in the absence of site specific data. The specific nature of this extrapolation procedure will in large part be determined by the outcome of the analysis of similar streams within particular strata. At one level, the monthly averaged recommended instream flows for similar streams can be used for any other stream within a particular stratum. These can also be adjusted by watershed area specific to a stratum. Alternatively, it is possible to utilize multiple regression techniques to identify key stream channel characteristics such as bank full width, bank full cross sectional area, slope, etc., to define a few key channel characteristics that can be rapidly measured and used in the regression equations to estimate screening level instream flows. Validation of any extrapolation method within a particular stratum can be undertaken by the collection of similar data and subsequent modeling efforts.

Task VII Technology Transfer

Technology transfer is an important element of the project implementation. The purpose of this effort is to ensure that all participants are afforded the opportunity to acquire experience in the implementation of field collection methodologies, use of specific field equipment types, sampling strategies, and familiarity with analysis and modeling methods. An objective of the study should be the collaboration by all participants and the involvement of personnel in all aspects of the study process. Implementation of the study components should be accomplished within the existing frameworks of ongoing management and research programs at the State, Federal, and Tribal levels. Where possible, personnel within these programs should be provided training in the application of specific equipment, field methodologies, QA/QC procedures, analysis methods, component model calibration and simulation, and interpretation of study results. It should also be recognized that this focus ensures that all participants have a vested interest in the data, analysis methods, and interpretation of these results in light of specific management objectives. The specifics and mechanism of implementing technology transfer cannot at this juncture be determined. However, it is recommended that a series of technical training workshops should be arranged for a pre-defined schedule to meet the logistics needs associated with each technical element.

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